Seabed Prehistory:

Gauging the Effects of Marine Aggregate Dredging

Final Report

Volume VII

Happisburgh and Pakefield Exposures

Ref: 57422.37

February 2008

Wessex Archaeology

AGGREGATE LEVY SUSTAINABILITY FUND
MARINE AGGREGATE AND THE HISTORIC ENVIRONMENT

SEABED PREHISTORY:
GAUGING THE EFFECTS OF MARINE AGGREGATE DREDGING

ROUND 2
FINAL REPORT

VOLUME VII: HAPPISBURGH AND PAKEFIELD EXPOSURES

Prepared for:

English Heritage
1 Waterhouse Square
138-142 Holborn
London
EC1N 2ST

Prepared by:

Wessex Archaeology
Portway House
Old Sarum Park
Salisbury
SP4 6EB

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FINAL REPORT

VOLUME VII: HAPPISBURGH AND PAKEFIELD EXPOSURES

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Summary

This study forms Volume VII of the 'Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging - Final Report' commissioned by English Heritage (EH) and undertaken by Wessex Archaeology (WA). It was funded through Round 2 of the Aggregate Levy Sustainability Fund (ALSF) distributed by the Department for Environment, Food and Rural Affairs (DEFRA). The 'Final Report' comprises of eight volumes based on previous reports accomplished by WA for either EH or the Mineral Industry Research Organisation (MIRO), as part of Round 1 or Round 2 of the ALSF project 'Seabed Prehistory'.

In 2005 WA was commissioned by EH to undertake a geophysical survey to trace the Ancaster and Bytham palaeoriver systems offshore of locations at Happisburgh, Norfolk and Pakefield, Suffolk. This project has been funded through the ALSF and was additional to the Round 2 'Seabed Prehistory' project.

This project was inspired by the current research on the palaeoriver systems in East Anglia which extend into the southern North Sea basin. The archaeological potential of these systems has been established on land but as yet their offshore potential had not been assessed.

The principal objective of the Happisburgh and Pakefield Exposures project was to trace sediments of known archaeological potential onshore into the offshore marine environment. The fine-grained sediments onshore are unique and have changed our understanding of the earliest occupation of Britain. Finds within these sediments have demonstrated that human occupation of north-west Europe started earlier than hitherto thought, *c.* 700,000 years ago. The survival of these deposits at the base of the cliffs at Happisburgh and Pakefield is unexpected considering their character and nature, and the series of geomorphological processes that have affected them. As these deposits reside at the base of the cliffline and on the foreshore there is a possibility for their survival offshore. If traced, this would allow the geophysical signatures of fine-grained deposits to be assessed and improve methodologies to effectively survey these deposits in the future.

In order to achieve the project objectives a geophysical survey was undertaken. WA carried out the geophysical survey at sites off the coast of Suffolk and Norfolk aboard the R/V *Wessex Explorer* between the 1st and 6th June 2006.

Based on preliminary interpretations of the Pakefield and Happisburgh geophysical data, a further variation to the project was developed. This involved a vibrocore survey at three locations identified from the geophysical data at the Pakefield site. The vibrocoring was

undertaken by Gardline Surveys on the 19th July 2006, from the S/V *Flatholm*. The aim of the geotechnical survey was to confirm the geophysical interpretation, and to provide environmental samples for assessment, analysis and dating.

A high quality dataset was acquired and the results show a sedimentary sequence pre-dating the Anglian Glaciation, overlain by Holocene sands.

At Pakefield, sediment units were observed on the geophysical data that matched the extent and form of those described at the base of the cliff exposures. Vibrocore analysis and environmental assessments and analyses enhanced the geophysical data interpretation and enabled a better understanding of the sediments depositional environments. This facilitated correlation between onshore and offshore sediments. Although sediments of the Cromer Forest-bed Formation no longer exist offshore within the study area, older sediments interpreted as the Wroxham Crag Formation were identified. It was within the upper part of the Wroxham Crag Formation that worked flint was found onshore. The survey at Pakefield successfully demonstrated that sediment units identified onshore can be traced offshore and that not all of these very early terrestrial sediments that are now in submerged areas have been removed by glacial processes and/or marine erosion.

At Happisburgh, the survey was carried out further from the coast in deeper water to that of Pakefield due to the presence of beach groynes that posed a risk to the equipment. Only sediments interpreted as older than those identified in the cliff exposures and on the foreshore were identified on the geophysical data. However, it is possible that younger sediments relating to the Cromer Forest-bed Formation observed on the foreshore and related early Middle Pleistocene sediments may be preserved closer to the shoreline.

The Happisburgh and Pakefield Exposures Project has demonstrated that fine-grained deposits can be identified and surveyed by use of geophysical and geotechnical methodologies in nearshore areas, even were deposits are close to the seabed. The results of the project will directly inform future marine aggregate dredging, both in terms of baseline knowledge of the historic environment in aggregate dredging areas, and the methodologies that can be used by industry to assess and mitigate any significant effects of dredging.

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English Heritage (EH) commissioned this project supported by the Aggregates Levy Sustainability Fund (ALSF). Wessex Archaeology (WA) would like to thank Dr Helen Keeley, Dr Virginia Dellino-Musgrave and Kath Buxton for their help and support.

The geophysical fieldwork was undertaken by Louise Tizzard, Cristina Serra, Dr Stephanie Arnott and Dr Paul Baggaley of WA onboard the R/V *Wessex Explorer*. WA would like to thank the captain of the *Wessex Explorer*, Chris Hayes, and his crew for their assistance during the fieldwork

The geotechnical survey was undertaken by Gardline Surveys Ltd. onboard the S/V *Flatholm* and was supervised by Jack Russell of WA. WA would like to thank the crew of the S/V *Flatholm* and Gardline Surveys for their assistance during this phase of the fieldwork. Processing and interpretation of the cores was carried out by Jack Russell and Dr Dietlind Paddenberg.

Louise Tizzard and Dr Stephanie Arnott carried out the geophysical processing. Louise Tizzard and Jack Russell compiled this report, which was edited by Dr Dietlind Paddenberg. Figures were compiled by Kitty Brandon, and Stuart Leather managed the project for WA.

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1. INTRODUCTION

1.1. PROJECT BACKGROUND

1.1.1. In 2005, Wessex Archaeology (WA) was commissioned by English Heritage (EH) to compile the final synthesis of the research project 'Seabed Prehistory – Gauging the Effects of Marine Aggregate Dredging'. The project synthesis was funded through Round 2 of the Aggregate Levy Sustainability Fund (ALSF) distributed by the Department for Environment, Food and Rural Affairs (DEFRA) (see **Volume I**).

1.1.2. Round 1 of the 'Seabed Prehistory' project was undertaken between 2003 and 2004 as part of the Sustainable Land Won and Marine Dredged Aggregate Minerals Programme (SAMP), funded by Round 1 of the Aggregate Levy Sustainability Fund (ALSF) and administered by MIRO on behalf of the former Office of the Deputy Prime Minister (ODPM), now Department for Communities and Local Government (DCLG).

1.1.3. The project was extended to Round 2 in order to assess the application of the Round 1 methodologies to aggregate dredging zones with different geoarchaeological characteristics. Round 2 comprised different components, each component funded through either EH or MIRO, under the ALSF funding for Round 2. Each component was an independent stand alone project, resulting in the eight volumes of this report. **Table VII.1** provides an overview of all volumes of 'Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging - Final Report', **Volumes I-VIII** (Wessex Archaeology 2007):

Volume	Title
I	Introduction
II	Arun
III	Arun Additional Grabbing
IV	Great Yarmouth
V	Eastern English Channel
VI	Humber
VII	**Happisburgh and Pakefield Exposures**
VIII	Results and Conclusions

Table VII.1: Overview of the volume structure of this report.

1.1.4. This report is **Volume VII** in the series and sets out the Round 2 investigations into the Happisburgh and Pakefield Exposures. It is an updated version of a previous 'Seabed Prehistory' project report for EH (Wessex Archaeology 2006).

1.1.5. The Happisburgh and Pakefield Exposures project aimed to trace the Ancaster and Bytham palaeoriver systems offshore of locations at Happisburgh, Norfolk, and Pakefield, Suffolk. It arose as the result of the current research on palaeoriver systems in East Anglia that extend into the southern North Sea Basin. The archaeological potential of these systems had been established on land (Parfitt *et al.* 2005) but their offshore potential had not been addressed previously. Additionally, the project aimed to assess the applicability of survey methodologies to the nearshore environment, to discriminate and identify sediments within 5m of the seabed, and to assess the possibilities of tracing cliff exposures offshore.

1.1.6. The inspiration for the project came from the unique opportunity to trace very early sediments of known archaeological potential onshore into the offshore marine environment. The fine-grained sediments onshore are unique and have changed our understanding of the earliest occupation of Britain. Finds within these sediments have demonstrated that human occupation of north-west Europe may date to *c.* 700,000 rather than *c.* 500,000 years ago as previously thought. The survival of these deposits at the base of the cliffs at Happisburgh and Pakefield is unexpected considering their character and nature, and the series of geomorphological processes that have affected them. As these deposits reside at the base of the cliffline and on the foreshore there is a possibility for their survival offshore.

1.1.7. Demonstrating the survival of pre-Devensian fine-grained sediments offshore would radically alter the interpretations for very early prehistoric material in the seas around the UK, and therefore change the advice given to aggregate companies in the course of licence applications.

Study Area

1.1.8. The geophysical survey comprised two main study areas focussing on the near-shore deposits at Pakefield and Happisburgh (**Figure VII.1**).

1.1.9. A series of investigation lines off the coasts of Suffolk and Norfolk were also undertaken, to try and locate the edges of any channels that may be part of the Bytham or Ancaster palaeoriver systems. Specifically, the survey lines were to be run through Gorelston Road, Caister Road and Barley Picle, which were based on Dr Brian D'Olier's hypothesis that the Bytham River might take a northward route offshore, and that the sandbanks situated either side of Barley Picle possibly form the edges of a palaeochannel (D'Olier *pers. comm.* 2006). At Barley Picle one long line orientated north-south along the channel was surveyed and three cross-lines orientated east-west were acquired. A north-south orientated survey line was run through both the Gorelston Road and Caister Road channels (**Figure VII.1**).

1.1.10. The coordinates of the Happisburgh study area (WGS 84, UTM zone 31) are given in **Table VII.2.**

Easting	Northing
400610	5854946
400713	5855030
400452	5855253
400539	5855333
400446	5855422
400548	5855525

Easting	Northing
400261	5855760
400579	5856141
402921	5853993
402617	5853613
402482	5853739
402377	5853619
402163	5853785
402070	5853674

Table VII.2: Coordinates of the Happisburgh study area (WGS 84, UTM zone 31).

1.1.11. The coordinates of the Pakefield study area (WGS 84, UTM zone 31) are given in **Table VII.3.**

Easting	Northing
414150	5812052
414306	5811980
414357	5812104
414572	5812045
414627	5812206
415231	5812042
415089	5811645
415075	5811435
414992	5811091
415052	5809468
414647	5809447
414549	5809571
414175	5809521
413562	5809712
413734	5810996
413896	5811486

Table VII.3: Coordinates of the Pakefield study area (WGS 84, UTM zone 31).

1.2. Geoarchaeological Background

1.2.1. Specific research is currently being undertaken into the palaeogeography, sedimentology and archaeology of the pre-Anglian river systems of East Anglia by several research institutes, lead by Professor James Rose from Royal Holloway University of London. The research seeks to map, date and characterise the deposits associated with these river systems, and to understand the archaeological material found within them. The research draws upon and contributes to many fields of investigation in Quaternary science, including the history of climate change, the history of glaciation, environmental change including the environment in which early humans lived, and details of human inhabitation. The work also involves methodological developments in dating, lithostratigraphy and biostratigraphy.

1.2.2. Recent research has identified archaeological artefacts contained within the present day beach stratigraphy on the coast at Happisburgh and Pakefield, East Anglia (Parfitt *et al*. 2005).

1.2.3. The artefacts are thought to be associated with the Ancaster and Bytham River deposits at Happisburgh and Pakefield, respectively. The Ancaster River had a catchment area that encompassed much of northern England and transported sediments to northern East Anglia, but the river has since been destroyed by glaciation. The Bytham River system was part of a catchment area covering middle and eastern England (**Figure VII.1**). During the Anglian glaciation (OIS 12) the Bytham River system was destroyed by glacial erosion and no expression in the present landscape remains (Rose *et al.* 2001). Flint tools have been found in the floodplain and estuarine deposits of both the Ancaster and Bytham river systems, which can be observed in the coastal cliff sections at Happisburgh and Pakefield.

Happisburgh

1.2.4. The exposed cliff section at Happisburgh comprises glacial till belonging to the Lowestoft and Happisburgh Formations. The Lowestoft Formation was deposited by the Anglian glaciation (OIS 12), during which ice sheets reached their maximum extent in Britain. The Lowestoft Formation overlies the Happisburgh Formation (Moorlock *et al.* 2000), deposited during the Happisburgh glaciation, which was the first Middle Pleistocene glaciation of lowland eastern England and the adjacent North Sea basin, probably dating to OIS 16 (Lee *et al.* 2004).

1.2.5. Sediments of the Cromer Forest-bed Formation are exposed on the foreshore at Happisburgh and are overlain by the glacial till. The Cromer Forest-bed Formation is a pre-glacial deposit of Cromerian Complex age (OIS 19) comprising primarily organic detritus muds and sands laid down within channels and on the floodplains of rivers (Parfitt *et al.* 2005). The thickness of this formation is unknown and, based on sites along the Norfolk coast, is likely to overlie the Wroxham Crag Formation and Norwich Crag Formation. Both the Wroxham Crag and Norwich Crag sediments were deposited in a predominantly marine coastal shelf environment (Lee *et al.* 2006).

1.2.6. Within the sediments of the Cromer Forest-bed Formation significant evidence of wood and plant remains have been identified. Also, it is documented that in 2000 a hand-axe was found *in situ* within these deposits (Geological Society of Norfolk 2002).

1.2.7. An overview of the lithostratigraphy of the cliff section at Happisburgh is provided in **Table VII.4**. Chronostratigraphy dates are taken from Lee *et al.* (2004).

Lithostratigraphy	Sediment	Environment	Chronostratigraphy
Lowestoft Formation	Till	Glacial	Anglian Glaciation (OIS 12)
Happisburgh Formation	Till	Glacial	Middle Pleistocene (OIS 16)
Cromer Forest-bed Formation	Organic fine-grained sediments	Alluvial/estuarine	Comerian Complex (OIS 19)
Wroxham Crag Formation	Predominantly quartoze sands and gravels	Coastal shelf	Early Middle Pleistocene (Pre-OIS 20)
Norwich Crag Formation	Shelly sand, silt and clay	Coastal shelf	Early Pleistocene (Pre-OIS 20)

Table VII.4: Litho- and chrono-stratigraphy of the Happisburgh cliff section.

Pakefield

1.2.8. The Pakefield site is thought to be on the course of the Bytham River, which has produced a series of Lower Palaeolithic sites along its length. The cliff section at

Pakefield is similar to that at Happisburgh. At the base of the cliff the How Hill Member of the Wroxham Crag Formation is exposed, overlain by the Cromer Forest-bed Formation, which is in turn overlain by the glacial sediments of the Happisburgh and Lowestoft Formations (Lee *et al.* 2006).

1.2.9. Archaeological excavations at Pakefield have uncovered 32 worked flints, including a simple flaked core, a crudely retouched flake and a quantity of waste flakes. The artefacts are thought to be consistent with Mode 1 technology (Parfitt *et al.* 2005). The artefacts were all found in clear stratigraphical contexts relating primarily to the interglacial infill of a channel incised into Early Pleistocene marine sediments; the Rootlet and Unio-beds of the Cromer Forest-bed Formation. One flint was found in context in the underlying Wroxham Crag Formation sediments. Fossils, plant and beetle remains indicate that the floodplain would have provided a resource-rich environment for early humans, along with flint-rich river gravels providing raw materials for tool manufacture (Parfitt *et al.* 2005).

1.2.10. The floodplain deposits containing flint artefacts are the earliest indication of human occupation in Britain. Based on palaeomagnetism, lithostratigraphy and biostratigraphy deposits have been dated as OIS 17 (*c.* 680 ka) at the youngest, and may be as old as OIS 19 (*c.* 750 ka) (Parfitt *et al.* 2005:1011; Lee *et al.* 2006:174-176). The discovery of artefacts at Pakefield demonstrates a longer human occupation of north-west Europe than hitherto thought, pre-dating other evidence by as much as 200,000 years.

1.2.11. The depth of the floodplain sediments offshore is not known, though the low levels of terrace aggradations, long profile and low gradient of the Bytham River (Lee *et al.* 2004; Parfitt *et al.* 2005; Lee *et al.* 2006) indicate that the deposits are likely to be at the level of the seabed offshore of the coastal site.

1.2.12. Both the artefacts and artefact-bearing sediments at both Happisburgh and Pakefield survive because they have been protected by the overlying deposits of the Happisburgh Formation and have only now been exposed by active coastal erosion. Where this glacial protection has not been present the earlier landscape has been destroyed by persistent sub aerial weathering and erosion.

1.2.13. The offshore geology of the coast of East Anglia is generally defined as Westkapelle Ground Formation, comprising clays and sands deposited in an open shelf marine environment and dating to the early Lower Pleistocene (Cameron *et al.* 1992). The upper sediments of this formation are contemporaneous with the onshore Norwich Crag Formation. Deposits of the Yarmouth Roads Formation may be found locally, overlying the Westkapelle Ground Formation. The Yarmouth Roads Formation comprises sands and clays of fluvatile and estuarine origin and dates from the Lower Pleistocene to Middle Pleistocene (Cromerian Complex) (Cameron *et al.* 1992). The Yarmouth Roads Formation includes sediments equating to the onshore Wroxham Crag and Cromer Forest-bed Formations.

1.2.14. The original course of the Ancaster and Bytham Rivers offshore is unknown. However, it has been suggested that away from the present day coast the Bytham River may have taken a northern route through what is now known as Barley Picle (D'Olier *pers. comm.* 2006). Barley Picle is a channel orientated north-south approximately 6km off the coast (**Figure VII.1**) and large sandbanks are present on either side, which are proposed as marking the edge of a palaeochannel.

1.2.15. Prior to this survey no geophysical surveys have been directed at tracing the remnant deposits of the Ancaster and Bytham rivers offshore.

2. SURVEY METHODOLOGIES

2.1. OVERVIEW

2.1.1. The geophysical survey comprised a shallow seismic survey, which allowed the sub-surface geology to be interpreted and individual geophysical horizons to be digitally modelled, and a sidescan sonar survey, which allowed the seafloor sediments to be interpreted. Data were collected in two small areas off the coast of Pakefield and Happisburgh respectively. Additional survey lines were run in the vicinity of Gorelston Road, Caister Road and Barley Picle, off the coast of Great Yarmouth (**Figure VII.1**).

2.1.2. Based on preliminary interpretations of the Pakefield and Happisburgh geophysical data, a further variation to the project was developed. This involved a vibrocore survey at three locations identified from the geophysical data at the Pakefield site. The aim of the geotechnical survey was to confirm the geophysical interpretation, and to provide environmental samples for assessment and analysis.

2.2. GEOPHYSICAL SURVEY

Technical Specifications

2.2.1. The geophysical survey was carried out by WA aboard the R/V *Wessex Explorer* between the 1^{st} and 6^{th} June 2006. Throughout the survey all positions were expressed in WGS84, UTM zone 31N coordinates. All depth references have been reduced to Ordnance Datum Newlyn (OD).

2.2.2. Bathymetry, sub-bottom profiler and sidescan sonar data were acquired on all of the investigation lines, with the exception of those in the deep waters of Barley Picle where no sidescan sonar data was acquired, due to the excessive length of cable out and the number of submerged fishing traps in the area causing hazards to submerged towed equipment. A total of approximately 136 line kilometres of data were collected during the survey.

2.2.3. The area surveyed near-shore Pakefield was approximately 3.4km^2 in size (2.6km long and 1.3km wide) comprising 11 survey lines with a line spacing of around 100m. This line spacing was used in order to achieve adequate coverage of the area in the limited time available. The lines closest to shore had to be surveyed at high-tide in order to limit the chances of grounding the vessel or towed equipment. All lines were orientated south-west to north-east following the coastline. No lines were run perpendicular to the shoreline because of the shallow water (<5m) and the risk of grounding the towed equipment.

2.2.4. At Happisburgh the survey comprised four long lines running parallel to the coast between Waxham and Happisburgh. A focused survey comprising four additional lines was conducted directly off the coast from Happisburgh. The study area was limited to the north by a guard vessel protecting a newly trenched exposed pipeline (no vessels towing equipment were allowed near the area) and limited to the west by the steeply sloping beach profile and the presence of groynes. Although the survey was conducted at high tide the exact location of the groynes could not be sighted and the risk to the towing equipment and vessel was considered high. For these reasons no lines were run perpendicular to the coast at Happisburgh. However, data was collected to within 400m off the coast.

2.2.5. Positioning for the survey was provided by a Leica MX412 DGPS Professional navigator system. The navigation data for this survey was recorded digitally using Ilex Harbourman software and a position was logged every second. The recording system, echo sounder and tow fish were all interfaced with the GPS ensuring the navigation parameters were consistent for all equipment throughout the survey.

2.2.6. Single beam bathymetric data was recorded throughout all stages of surveying and was acquired using a Knudsen 320M single beam echosounder. The echosounder transducer was mounted to the survey vessel, and the transducer draught was measured and entered into the echosounder to obtain depths relative to the sea-surface. A TSS DMS 2.05 motion sensor was rigidly mounted above the transducer to measure the vertical displacement (heave) and attitude (roll/pitch) of the vessel; this data was interfaced with the echosounder. The accuracy of the draught and velocity offsets were checked regularly throughout the survey using the bar check method. The corrected bathymetric data were recorded digitally and on the echo sounder paper trace, and interfaced with the navigation data using Ilex Harbourman software.

2.2.7. For the nearshore surveys at Happisburgh and Pakefield the depths were reduced using the tide gauge at Lowestoft Harbour (as supplied by the Proudman Oceanographic Laboratory (www.pol.ac.uk)). For the investigation lines off Great Yarmouth, water levels were acquired using a Valeport Midas Water Level Recorder. These data were used to reduce the depth data, which were then tidally adjusted making reference to the Lowestoft tide gauge data. Chart Datum (Lowestoft) relative to Ordnance Datum (Newlyn) is -1.50m.

2.2.8. Sub-bottom profiler data were acquired using two systems: a chirp and a surface-tow boomer system.

2.2.9. The chirp system used was the new EdgeTech 3100P portable sub-bottom profiling system using a SB-126S tow vehicle. The chirp is a high resolution wideband frequency modulated sub-bottom profiler. The system transmits a frequency modulated pulse that is swept over a full spectrum frequency range (in this case 2-12 kHz). The acoustic return that is received at the hydrophones is passed through a pulse compensation filter. This results in high resolution profiles of sub-bottom stratigraphy. The vertical resolution, using 2 – 12 kHz frequency, is 8cm, and in an area of sand, which is typical for the study areas of concern, the typical sub-seabed penetration is expected to be six metres.

2.2.10. Chirp data were digitally recorded on an EdgeTech model 3100P topside processor and laptop. The data were recorded in SEG-Y format and were then converted to Coda format for processing and interpretation.

2.2.11. An Applied Acoustic Engineering AA200 surface-tow boomer plate housed on a catamaran with an EG&G 265 8 element external hydrophone array was used throughout the survey. The boomer plate and hydrophone were towed approximately 15 metres behind the vessel to starboard and port respectively with a separation of approximately four metres. The offsets of the tow point to the echosounder were measured for use in the data processing.

2.2.12. The chirp was used for the small study areas at Pakefield and Happisburgh. Based on previous work at Pakefield (Parfitt *et al.* 2005) it was perceived that interpretation within the top two metres would prove critical in tracing the onshore deposits offshore. The chirp system generally produces a smaller seabed pulse compared to the boomer system. As such, less data is masked beneath the seabed pulse on chirp data, providing resolute data within the first two metres below the seabed. Also, due to the higher frequency settings the chirp provides more resolute data compared to the boomer source. Hence, the chirp was considered a viable option for these surveys. For the investigation lines in deeper water the surface-tow boomer system was used. The aim of the investigation lines was to provide an overview of the general geology of the area and the boomer was chosen as it provides data to a greater penetration sub-seabed albeit at a lower resolution than the chirp system.

2.2.13. A paper copy of all the sub-bottom profile data was retained by WA for interpretation and processing purposes.

2.2.14. During this survey an EdgeTech 4200-FS dual frequency digital sidescan sonar was used. This system collects data at 120kHz and 410kHz simultaneously. Digital dual frequency systems are widely used in the marine aggregate industry for both prospecting and seabed sediment mapping. The EdgeTech 4200-FS is a new system which also enables different range settings to be applied to the different frequencies. This allows high frequency data to be acquired at a short range resulting in higher resolution data, whilst simultaneously recording low frequency, long range data.

2.2.15. The sidescan sonar towfish was towed directly behind the survey vessel. The data quality was optimised by adjusting the height of the fish by changing the length of the tow-cable (between 1 and 50m) to account for changes in water depth and vessel speed.

2.2.16. High frequency data was acquired at a range of 75m; low frequency data was acquired at a range of 150m. This ensured full seabed coverage at both frequencies for the two main study areas. The sidescan sonar data was used to assess seabed sediment types across the survey area and was used in conjunction with the sub-bottom profiler data to interpret the nature of the uppermost sediment unit. The data was used in conjunction with the bathymetry data to assess the geomorphology of the area. The sidescan sonar data were also used to inform the design of the vibrocore and grab sampling surveys to ensure that there was no debris, outcropping geology or other hazards in the planned sample locations.

2.2.17. The sidescan sonar data was collected digitally on a workstation using Coda GeoSurvey software in *.xtf format and stored on hard disk as date/time referenced files for post-processing and the production of sonar mosaics.

Data Processing

2.2.18. The single beam echosounder data were processed using Ilex Harbourman software. This included correcting the data for tides and editing any erroneous points from the data. Based on the frequency of data acquisition (every second) and the average speed of the vessel (3 – 4knots) the data was gridded to one metre cells and the corrected, processed bathymetry was then exported as an ASCII text file for contouring and displaying using the Surfer software (version 7.1) package.

2.2.19. The processing of the digital seismic data was undertaken using Coda Geosurvey software, which is a standard package for processing and interpreting single channel seismic data. This software allows the data to be replayed one line at a time with user selected filters and gain settings in order to optimise the appearance of the data for interpretation. Coda Geosurvey then allows an interpretation to be applied to a line of data by identifying and selecting boundaries between layers.

2.2.20. The seismic data is collected and interpreted with two-way travel time (TWTT) along the z-axis, not depth. Therefore, to convert the TWTT to the interpreted boundaries into depths, the velocity of seismic waves through the geology must be known or estimated. For this project the velocity of the seismic waves was estimated to be 1600 m/sec, which is a standard estimate for shallow, unconsolidated sediments of the type being studied in this survey (Sheriff and Geldart 1983; Telford *et al.* 1990).

2.2.21. Once the seismic data had been interpreted the position of the boundaries could be exported in the form of x, y, z text files, where z was now the calculated depth in metres below OD, not the TWTT.

2.2.22. The sidescan sonar data was acquired and post-processed using Coda Geosurvey software and a sonar mosaic of the seafloor was produced.

2.3. GEOTECHNICAL SURVEY

2.3.1. Based on provisional geophysical data interpretation of the Pakefield and Happisburgh sites, a total of five vibrocores from three locations were acquired at the Pakefield site. The vibrocoring was undertaken by Gardline Surveys on the 19th July 2006, from the S/V *Flatholm*.

2.3.2. A high powered vibrocore unit was used for the survey. A 5m core barrel was deployed in order to obtain optimum depths indicated by the geophysical data. Date, time, position and water depth at each site were recorded.

2.3.3. Three cores (one core from each site location) were collected for archaeological recording purposes. At two of the three site locations (**VCP1** and **VCP3**), additional cores in opaque casings specifically for optically stimulated luminescence dating (OSL) were acquired.

2.3.4. After the fieldwork was completed the cores were transported to WA's environmental processing laboratory, where the cores were archaeologically recorded. One core from each site was split longitudinally, photographed and logged. The core logs provided details of the depth to each sediment horizon and the character of the sediment. Sedimentary characteristics recorded included texture, colour and depositional structure (**Appendix I**).

2.3.5. Following this, the logs were compared in terms of their vertical distribution throughout the study area. This was achieved by adjusting the water depths for tides and plotting the cores in sections referenced to OD heights.

2.3.6. The depositional and sedimentary boundaries identified in the core logs were then compared with the geophysical data interpretation in order to characterise the geophysical units identified at the core locations and to extrapolate the units throughout the site.

2.3.7. Environmental samples were taken from relevant deposits in order to provide chronological and environmental information relating to their formation. Samples taken from vibrocores **VCP2** and **VCP3** were assessed for pollen (**Appendix II**), diatoms (**Appendix III**), ostracods (**Appendix IV**) and foraminifera (**Appendix V**).

3. RESULTS

3.1. GEOPHYSICAL DATA

Happisburgh

3.1.1. Within the Happisburgh study area, water depths vary between 11.1m and 15.9m below OD (**Figure VII.2**). The seabed is at its shallowest towards the south-west extreme of the site. The seabed deepens to a maximum of 15.9m below OD in the centre of the site before shoaling to the east.

3.1.2. Throughout the survey the sidescan sonar data was of generally good quality with both high and low frequency data showing data to the full extent of the range. However, in Happisburgh some striping was apparent on the data particularly on the high frequency channels. This was caused by movement of the sidescan sonar fish affected by sea-swell.

3.1.3. The seabed appears predominantly sandy with some small areas of boulders to the western limit of the site. A large area of low reflectivity measuring approximately 1,800m x 50m is observed orientated north-west to south-east, parallel to the survey lines (**Figure VII.2**). There is no corresponding feature identified in the bathymetric data but it is possible that this feature is a small sandbank or subtle change in sediment type.

3.1.4. A large anomaly is observed on the sidescan sonar data (**Figure VII.2**) comprising an area measuring 66m x 37m of predominantly dark reflectors, some of which exhibit acoustic shadows. The structured arrangement of the reflectors indicates it is probably anthropogenic in origin. The site is located at the position of an obstruction on Admiralty Chart 106 (2004). This indicates that the obstruction is upstanding by approximately two metres. Analysis of the bathymetric data over the site indicates the feature is upstanding by 1.6 metres. The obstruction is also observed on the chirp data standing proud of the seabed.

3.1.5. The sub-bottom boomer data was of variable quality dependent on the sea state at the time of acquisition. However, all acquired data was considered fit for interpretation purposes. Penetration of sediments sub-seabed varied depending on quality of the data and the geology; maximum penetration of around 30m sub-seabed was observed at the Happisburgh site.

3.1.6. Chirp data was generally of good quality. A maximum penetration of around 6m was achieved. Given the likely sediment type this was to be expected. In order to ensure optimal data quality the chirp tow fish should ideally be towed between 3 and 5m above the seabed. Due to operational difficulties at Happisburgh (see **Section 2.2.8**) this was not possible. However, the data was considered to be adequate for processing and interpretation.

3.1.7. On the sub-bottom profiler data three distinct units are observed (**Units A, B, C**). All units are observed on the surface-tow boomer data (**Figure VII.3**) and the chirp data (**Figure VII.4**).

3.1.8. The reflector marking the top of **Unit A** lies horizontal, parallel to the seabed at the north of the site at around 1.5m sub-seabed (around 15m below OD) and deepens to a maximum observed depth of 23.5m sub-seabed (35m below OD). To the south of the Happisburgh site this reflector continues to deepen. This reflector is not observed on the chirp data at a depth below 6m sub-seabed.

3.1.9. **Unit B** overlies **Unit A** and comprises a series of weak, parallel and sub-parallel reflectors. To the very north of the study area this unit is absent and **Unit C** directly overlies **Unit A**. South of this position the unit gradually thickens to in excess of 15m thick towards the southern edge of the site. The depth to the top of the unit varies between 1.6m sub-seabed (15.6m below OD) in the east to 8.4m sub-seabed (22.2m below OD) in the west.

3.1.10. **Unit C** is consistent across the Happisburgh site and consists of a seismically transparent unit. The thickness of the unit varies; it is approximately 1.6m in the east and thickens to 8.4m in the west. On the chirp data localised internal reflectors were observed within 2m of the seabed (between 12.2 and 17.3m below OD). These are not observed clearly on the surface-tow boomer data.

Pakefield

3.1.11. The water depths at the Pakefield site vary between 3.4m and 8.5m below OD (**Figure VII.5**). The shallowest data is, as one would expect, close to the shoreline. From the shoreline the seabed gradually deepens to a depth of 7.0m below OD before shoaling to the east to a depth of around 4.4m below OD. To the south-east of the site the seabed deepens to its recorded maximum of 8.5m below OD.

3.1.12. The sidescan sonar mosaic (**Figure VII.5**) shows the shoreline on the western edge of the site marked by a linear dark reflector running parallel to the coastline. Directly to the east of the shoreline, noise in the water column affecting the data is observed. This is due to water turbulence in the very shallow water. Throughout the remainder of the site the sidescan sonar data indicates a covering of sand.

3.1.13. Four seismic units, represented by three distinct seismic reflections, were observed on the chirp data acquired at the Pakefield site (**Figure VII.6**). The chirp data was generally of good quality. A maximum penetration of around 6m was generally achieved. Given the likely sediment type this was to be expected.

3.1.14. **Unit A**, the deepest unit, is generally a seismically strucureless layer with occasional weak sub-parallel reflectors. The base of this unit is not observed on the data and the top of this unit is marked by a strong reflector. **Unit A** is observed throughout the site and the top of the unit is generally observed between 0.5m and 6.4m below the seabed (4.4m and 11.9m below OD).

3.1.15. **Unit B** is observed throughout the site. Seismically, to the south and west of the site the unit consists of a relatively transparent unit with few faint reflectors. As this unit thickens to the north and east the unit becomes more layered with numerous parallel horizontal reflectors. The surface of this level undulates throughout the site and varies between within 0.5m and 4.3m sub-seabed (9.2m below OD). Within 200m of the coast the base level of this unit is observed within 0.5m of the seabed (**Figure VII.7**). The nature and depth of the base of this unit in the south-west is similar to that described by Parfitt *et al.* (2005).

3.1.16. **Unit C** lies conformably on **Unit B** and represents a distinct sediment change. Seismically the unit is transparent and is observed throughout the majority of the site, except where the underlying **Unit B** outcrops at the seabed.

3.1.17. **Unit D** is the uppermost unit observed directly beneath the seabed. The base of this unit is only observed where it is thick enough for the seabed reflector and the reflector marking the base of the unit to be discriminated. Generally, the unit is observed where it is greater than 0.5m thick. The maximum observed thickness of the unit is 2.36m.

3.1.18. To the south-east of the site a small area of blanking was observed on the data at a depth of approximately 3m sub-seabed. This is likely to indicate an area of shallow gas. The gas is only observed on two lines and is therefore likely to be a localised feature. Based on the geophysics it is not possible to state if the gas is generated at depth and has migrated towards the seabed or if the gas has been generated at shallow depths from organic layers within Tertiary sediments.

Other Areas

3.1.19. Investigation lines were run in three other areas: Barley Picle, Caister Road and Gorelston Road. The aim of these lines was to investigate any evidence of the Bytham River, or other channels of potential archaeological interest, offshore. Data were acquired initially at Barley Picle based on the theory that the formation of the sandbanks may represent remnant topographic features that may correspond to channel edges, possibly of the Bytham River (D'Olier *pers. comm*. 2006). The sub-bottom boomer data was of variable quality dependent on the sea state at the time of acquisition. However, all acquired data was considered fit for interpretation purposes.

3.1.20. Barley Picle is a north-south orientated channel situated approximately 6km off the coast of Great Yarmouth (**Figure VII.1**). On the banks of the channel the water depth is around 13m to 18m below OD. At the base of the channel the water depth reaches 48.2m below OD.

3.1.21. Five dominant units were observed in this area (**Figure VII.8**). The deepest unit, **Unit A**, comprises weak sub parallel reflectors. The base of this unit is not observed on the data. The top of this unit lies at approximately 48m below OD in the north. Heading south the reflector deepens to in excess of 73m below OD.

3.1.22. Based on the geophysical data, **Unit B** appears to lie conformably on **Unit A** and comprises a well structured unit with numerous reflectors observed indicative of a coarse sand and gravel unit. The thickness of **Unit B** varies between 4.5m and in excess of 25m. To the north of the line the base of the overlying **Unit C** is observed cutting into **Unit B** (**Figure VII.9**). To the north of this feature the base of **Unit C** is observed outcropping the seabed. To the south this reflector undulates between 33m and 43m below OD. The infill unit (**Unit C**) comprises lower amplitude reflectors indicating finer-grained sediments.

3.1.23. Overlying the in-fill unit (**Unit C**) is a localised unit of coarser-grained sediments indicated by a unit of high amplitude reflectors (**Unit D**). Where present, **Unit D** generally has a thickness of up to 4.5m. This unit is only observed in the northern and southern extremes of the channel. The uppermost significant reflector observed marks the base of a series of sandwaves (**Unit E**) that are observed along the length of the channel indicating strong seabed currents (**Figure VII.8**).

3.1.24. Along an east-west profile, banks are observed on either side of the channel. The banks are up to 16m thick. This appears to be one sediment deposition phase and appears to lie conformably on an undulating surface representative of **Unit C**. No cutting indicating any evidence of channelling was observed.

3.1.25. Along the Gorelston Road Channel investigation line the water depths varied between 5.5m to 8.0m below OD for the majority of the line, deepening to 21.4m below OD to the north. Generally, along the length of the line a series of horizontal and sub-horizontal reflectors overlain by a thin layer directly beneath the surface were observed. Off the coast to the north of Great Yarmouth there is evidence of a cut and fill structure (**Figure VII.10**).

3.1.26. An investigation line along the length of the Caister Road channel and one across the channel were collected to try and trace the channel observed on the Gorelston Road investigation line. Water depths varied between 6.9m below OD on the western bank and 25m below OD to the south. The sediments appear to comprise sands and gravels to a maximum observed depth of around 20m sub-seabed (42m below OD) underlying a thin layer of sediments, probable modern sediments. The upper unit varies from less than 1m to greater than 5m on the flank of the channel. No evidence of any channels or cutting of sediments was observed on the data.

3.2. Geotechnical Data

Pakefield Vibrocores

3.2.1. Three vibrocores **VCP1**, **VCP2** and **VCP3** were split longitudinally and recorded with depth to each sediment horizon noted, and the character, structure and form of the sediment described (**Figure VII.11**). Basic sedimentary characteristics were recorded including depositional structure as well as texture, colour and stoniness (cf. Hodgson 1976). The descriptions are presented in **Appendix I**.

3.2.2. From the descriptions a log was plotted for each core. The logs were then compared in terms of their vertical and lateral distribution across the study area referenced to Ordnance Datum.

3.2.3. On the basis of the descriptions and comparison of these to the geophysical results the major sedimentary units were ascribed four principal phases. The profile created by the phasing (**Figure VII.12**) provides an interpretative framework enabling comment to be made upon palaeoenvironmental and geoarchaeological significance of the sediments encountered.

3.2.4. **Unit A** (7.49m to 10.37m below OD) comprises clays, silts and sands and has been divided into two sub-units (**Figure VII.12, Appendix I**). **Unit Ai** (7.49m to 10.37m below OD) comprises sand with occasional lenses of silty clay and gravel inclusions. This unit was recorded in vibrocores **VCP2** and **VCP3**. **Unit Aii** (7.49m to 9.76m below OD) comprises interbedded fine sands and silty clay with laminar and convoluted bedding. This unit was recorded in vibrocores **VCP2** and **VCP3**.

3.2.5. **Unit B** (6.16m to 8.28m below OD) comprises sand with occasional silt and gravel. This unit has been divided into four sub-units. **Unit Bi** (7.21m to 8.28m below OD) comprises silty gravely sand with inclusions of wood and silty clay bands. This unit was recorded in vibrocores **VCP2** and **VCP3**. **Unit Bii** (6.16m to 8.19m below OD) comprises sand and gravelly sand with occasional broken shell inclusions. This unit was recorded in all three vibrocores. **Unit Biii** (7.84m to 7.92m below OD) comprises silty sandy gravel. This unit was recorded in vibrocore **VCP3**. **Unit Biv** (7.61m to 7.89m below OD) comprises sand with occasional broken shell and gravel inclusions.

3.2.6. **Unit C** (5.67m to 7.84m below OD) comprises sand with silt and shell inclusions. This unit was recorded in all three vibrocores.

3.2.7. **Unit D** (5.06m to 6.91m below OD) comprises fine sand and silty sand. This unit was recorded in all three vibrocores.

Pakefield Environmental Remains

3.2.8. Pollen (**Appendix II**), diatom (**Appendix III**), ostracod (**Appendix IV**) and foraminifera (**Appendix V**) assessments revealed that only pollen and foraminifera were preserved in significant numbers. Foraminifera were recovered from **Unit A** within vibrocore **VCP3** (**Appendix V**). Pollen were recovered from **Unit B** within vibrocore **VCP2** (**Appendix II**).

4. DISCUSSION AND CONCLUSIONS

4.1. Happisburgh

4.1.1. **Unit A** has been interpreted as the bedrock layer. Bedrock in this area is likely to comprise either Upper Cretaceous chalk or shelly sands of the Late Pliocene Red Crag Formation (Cameron *et al.* 1992; Cook 1991).

4.1.2. Based on their seismic nature and depth below OD, **Unit B** has been interpreted as part of the Westkapelle Ground Formation. This formation comprises an upward transition from grey clay, through sands, to muddy sand, and deposition took place in an open marine shelf environment during the Lower Pleistocene (Cameron *et al.* 1992).

4.1.3. **Unit C** is provisionally interpreted as an upper unit of the Westkapelle Ground Formation. Although a relatively strong reflector is observed marking the boundary between **Units B** and **C** (**Figure VII.3**) it is thought that this reflector represents a change in sediment type and not necessarily a formation change.

4.1.4. Localised reflectors observed on the chirp data directly beneath the seabed possibly represent the boundary between Pleistocene and Holocene sediments. The thickness of this unit is up to 1.8m in places, but, where measurable, is generally less than one metre thick. Although not observed on the chirp data as a continuous thickness, the sidescan sonar data indicates that the seabed is covered by a layer of sand throughout the site. These findings concur with the published BGS data (Larminie 1988).

4.1.5. It is difficult to associate the cliff exposures at Happisburgh with the geophysical data. On the foreshore, exposures of the Cromer Forest-bed Formation are observed just below zero metres OD and are likely to overlie the Wroxham Crag Formation; the thicknesses of these units are unknown. The seabed on the geophysics data is a minimum of 11.1m below OD, and although it is possible that the Wroxham Crag Formation may extend to this depth there is no geophysical data to directly support this. It is considered more likely that any Middle Pleistocene sediments will have been removed either during the Anglian Glaciation or by subsequent marine erosion. The sediments that have been interpreted as Westkapelle Ground Formation based on their seismic character are likely to be contemporaneous with the onshore Norwich Crag and Red Crag Formations, which are known to directly underlie the Wroxham Crag Formation (Rose *et al.* 2002:52 Table 1).

4.1.6. It is possible that younger sediments relating to the Cromer Forest-bed Formation observed on the foreshore may be preserved close to the shoreline. It was not possible to survey close to the shore using normal methodologies because of the presence of obstructions (groynes etc.). As such, there is still uncertainty whether any early Middle Pleistocene sediments (representing the Cromer Forest-bed Formation and the older Wroxham Crag Formation) are preserved within the 400m between the shoreline and the innermost survey line.

4.2. Pakefield

4.2.1. **Figure VII.13** illustrates the correlation between the geophysical reflectors and the units identified within the vibrocores.

4.2.2. **Unit A** is generally seismically structureless with occasional sub-parallel weak reflectors and is interpreted as a sand, silt and clay dominated unit. The reflector observed on the geophysical data marking the top of this unit is strong and is observed throughout the site and is represented in each of the three vibrocores (**Figure VII.13**). At the closest point to **VCP2** (7m to the east) the reflector marking the top of this unit is observed at 2.1m sub-seabed (7.2m below OD). This is likely to represent the abrupt sediment change in the vibrocore between compact well-sorted clayey silt and fine-grained well-sorted sand at 2.15m (7.25m below OD). However, as the vibrocore is situated away from the geophysical data and due to the numerous subtle changes noted in the core between 1.95 and 2.23m it is difficult to assess exactly which boundary is represented on the geophysics. **VCP2** indicates that **Unit A** comprises compact clayey silts (0.13m) overlying gravely sand, sandy wood, and sands. A weak reflector was observed on the chirp data at 3.4m sub-seabed (8.45m below OD). This possibly represents laminations within the bottommost sand layer.

4.2.3. At the closest point to **VCP3** (3.5m to the east) the reflector observed on the geophysics data marking the top of this unit is observed at 2.5m sub-seabed (8.5m below OD). This is likely to comply with the abrupt sediment change at 2.26m sub-seabed (8.28m below OD) in the core between the very stiff sandy silty clay and the overlying gravely sand (**Figure VII.13**). The difference in depths between the core and the geophysics data is likely to be because the core was acquired 3.5m to the west of the chirp survey line, and therefore small discrepancies, where slightly undulating surfaces are apparent, may occur.

4.2.4. At the site of **VCP1** there is a discrepancy between the depth of the top of **Unit A** in the vibrocore and on the geophysical data. The reflector that marks the top of this unit is observed at 3.3m sub-seabed (9.13m below OD), however, the corresponding surface of the clay unit in the vibrocore is at 2.3m sub-seabed (8.12m below OD); a discrepancy of 1m. This discrepancy could be due to differences in the sediment level between these two sites; the core is 13m away from the geophysical data. As the vibrocore was acquired away from the survey line the sediment depth for this position is unknown. Alternatively, the discrepancy could be due to the geophysical interpretation. On the chirp data a reflector interpreted as an internal reflector of the overlying **Unit B** is observed at a depth of 2.6m sub-seabed and may represent the top of **Unit A** as described in the core. This would match the geophysical data to the vibrocore; however, the seismic nature of the unit throughout the site is consistent, and therefore discounts this theory. There is no strong evidence in either the geotechnical or geophysical data to conclusively solve this issue.

4.2.5. **VCP2** and **VCP3** indicate that **Unit A** comprises sand layers varying from fine-medium-grained to medium-coarse-grained (**Figure VII.12**). Gravel inclusions comprising subangular to subrounded quartz and flint, and occasional clayey silt bands are observed within the unit. These sediments are overlain by stiff clays and silts. The sands have been interpreted as being deposited in a coastal environment, with the silts and clays being deposited in a lower energy environment, such as tidal estuaries, probably as part of the lower River Bytham river sequence.

4.2.6. Based on its seismic nature, **Unit A** has been interpreted as Westkapelle Ground Formation, described as a low amplitude unit containing a series of weak parallel reflectors, and is thought to date to the Early Pleistocene (Cameron *et al.* 1992). Based on the OD heights the reflector marking the top of this unit is comparable to what Parfitt *et al.* (2005) described as the top of a unit of Early Pleistocene marine sands. The sediments, and in particular the presence of flint within this section of the core indicates that these sediments possibly belong to the Norwich Crag Formation (Rose *et al.* 2001). In a cliff section drawn by J.H. Blake for the Geological Survey of England and Wales in 1890, a unit of laminated clays and sands was attributed to the Chillesford-beds (Parfitt *et al.* 2006). The currently named Chillesford Silty Clay member of the Norwich Crag Formation comprises interbedded silty clay laminations deposited in tidal estuaries (Rose *et al.* 2001). The age of the Norwich Crag Formation is comparable to the upper part of the Westkapelle Ground Formation.

4.2.7. **Unit B** lies unconformably on **Unit A**. Close to the shoreline this unit is low amplitude and structureless, however where the unit thickens to the east and the north of the site the seismic nature of the unit becomes increasingly layered indicating a series of sands and gravels. This unit is observed within each of the three cores. At the location of **VCP2 Unit B** is observed on the geophysics data between 1.0m and 2.1m sub-seabed relating to the abrupt boundaries observed in the core at 1.10m and 2.15m sub-seabed (6.16m and 7.21m below OD). The geophysics representing the top of **Unit B** is observed at 1.6m and 1.8m sub-seabed at the locations of **VCP3** and **VCP1**, respectively. In the vibrocores the relative boundaries are located at 1.82m and 1.78m sub-seabed (7.84m and 7.61m below OD) in **VCP3** and **VCP1**, respectively (**Figure VII.13**).

4.2.8. The vibrocores indicate that **Unit B** comprises sub-units of gravely sands and silty sandy gravels with frequent shells such as bivalves and inclusions of organic matter (**Figure VII.12**). Layers of sandy clayey silt are observed in **VCP3** and **VCP1**, possibly indicative of the layering observed on the geophysics data. The sediments in this unit have been interpreted as being deposited in a shallow marine/sublittoral environment. The layers of silt and clay indicate deposition in a lower energy environment.

4.2.9. The base of **Unit B** interpreted from the geophysical data is observed at a depth of less than 8m below OD. Close to where the flints were found in the cliff exposures, the depth to the base of **Unit B** is comparable to the depth of the unit described as the Wroxham Crag Formation onshore (Parfitt *et al.* 2005). Parfitt *et al.* (2005) described this unit as Early Pleistocene marine, estuarine and freshwater sediments. Lee *et al.* (2006) characterised this layer, were it crops out in the cliff exposure, in more detail. It is described as two sub-facies of the Wroxham Crag Formation comprising silty sands and gravels overlying silty sands and clayey silts. Similar sediments were observed in the vibrocores. Based on its stratigraphic nature and comparisons with the onshore literature **Unit B** is considered to belong to the Wroxham Crag Formation. It was within the upper part of the Wroxham Crag Formation were Parfitt *et al.* (2005) identified worked flint.

4.2.10. The Wroxham Crag deposits have been dated to several periods by different research projects (Bowen 1999, Rose *et al.* 2001, Lee *et al.* 2004; 2006). Geologically, the Wroxham Crag coastal deposits are correlated in terms of their lithostratigraphic characteristics and biostratigraphic position with the offshore Yarmouth Roads Formation (Cameron *et al*. 1992:102 Figure 91a-b).

4.2.11. On the geophysical data **Unit C** periodically overlies **Unit B** and where present the base of **Unit C** is represented by a strong reflector. **Unit C** comprises a seismically structureless unit and is observed within each vibrocore: between 0.6–1.0m, 0.6–1.6m and 1.0–1.8m sub-seabed at locations of **VCP2**, **VCP3** and **VCP1**, respectively. This agrees with the vibrocore sections where the unit is observed between 0.61–1.10m, 0.51–1.82m and 1.08–1.78m sub-seabed for **VCP2**, **VCP3** and **VCP1**, respectively (**Figure VII.13**).

4.2.12. The vibrocores indicate that **Unit C** comprises well sorted sands with occasional gravel and organic fragments in **VCP3**, and with silt layers observed towards the base of the unit in **VCP3** and **VCP1**. These sediments have been interpreted as having been deposited in a shallow marine environment and are thought to be modern.

4.2.13. **Unit D**, the uppermost layer, is observed where the thickness of the unit is greater than 0.5m. It generally comprises poorly sorted silty sands underlying silty sands with frequent broken shell and organics. This has also been interpreted as modern sediment. The two units (**Units C and D**) interpreted as being modern in origin are separated by a strong reflector on the geophysics and by an abrupt boundary in the vibrocores. This possibly represents two phases of modern sedimentation with the uppermost unit affected by modern day hydrodynamic forces.

4.2.14. In the cliff exposure the Cromer Forest-bed Formation overlies the Wroxham Crag Formation. Based on the geophysical and geotechnical data the Cromer Forest-bed Formation cannot be traced offshore. However, it is possible that the Cromer Forest-bed Formation is preserved between the foreshore and the western limit of the study area. Offshore, it is considered that any sediments of the Cromer Forest-bed Formation that were deposited have been removed during either the Anglian glaciation or subsequent marine transgressions and regressions.

4.2.15. To summarise, the sediments interpreted as the Norwich Crag Formation (**Unit A**) were deposited in the Bytham River and represent the lower part of the Bytham River sequence. The sediments observed offshore interpreted as the Wroxham Crag Formation (**Unit B**) represent tidal, intertidal and estuarine environments.

4.2.16. These sediments were deposited prior to the terrestrial sedimentation where the Cromer Forest-bed Formation was deposited on the floodplain of the River Bytham. The floodplain deposits no longer survive offshore within the study area, presumably removed by glacial or marine erosion processes.

Pakefield Environmental Remains

4.2.17. The environmental assessments and analyses of samples from vibrocores **VCP2** and **VCP3** are presented in **Appendices II, III, IV** and **V**. One diatom (**Appendix III**) and no ostracods (**Appendix IV**) were recovered from the samples. Foraminifera were recovered from **Unit A** in vibrocore **VCP3** and pollen were recovered from

Unit B in vibrocore **VCP2** (**Figure VII.12**). No environmental remains were recovered from **Unit C** or **Unit D**.

4.2.18. Foraminifera recovered from **Unit A** in vibrocore **VCP3** mainly comprised *Elphidiella hannai* and *Elphidium arcticum*. Both of these taxa are indicative of cold shallow marine and estuarine conditions. *Elphidiella hannai* is of some biostratigraphic value as it is common in the lower Pleistocene in the North Sea Basin and not known in the British Isles after the Anglian glaciation (**Appendix V**). No foraminifera were recovered from vibrocore **VCP2** and as such biostratigraphic confirmation of sedimentary correlation of Units between the cores was not possible using foraminifera.

4.2.19. Pollen were recovered from **Unit B** in vibrocore **VCP2**. The pollen data is defined as two distinct zones. Zone 1 is a single sample from the woody horizon in **Unit Bi**. This zone is dominated by alder with indicators of a damp fen environment (Osmundaceae and Cyperraceae) surrounded by mainly deciduous (birch, oak and holly) woodland. This is considered to be part of a temperate stage of an interglacial period. Zone 2 occurs within sedimentary **Unit Bii** of vibrocore **VCP2** and is dominated by Pine suggesting a boreal woodland environment which may be of pre-temperate or post-temperate zonation (**Appendix II**). Indicators of saline (dinoflagellates) brackish (*Plantago maritima*) and freshwater (*Pediastrum*) environments are all present in Zone 2 probably indicating a dynamic coastal environment.

4.2.20. Dating of Pleistocene sediments using pollen is not sufficiently reliable. However, ‘no Plio-Pleistocene exotic indicator taxa were observed’ (Scaife 2006, see **Appendix II**). The most analogous assemblage to the pollen recovered from this survey is that of ‘pre-Pastonian sediments’ described by ‘West (1980)’; ‘This assemblage appears, in fact, to be more analogous to the offshore Pakefield sequence than are the pollen assemblages at Pakefield which are attributed to the overlying Pastonian and Cromerian sequences’ (Scaife 2006, see **Appendix II**).

4.2.21. Correlation of sediments between cores was not possible using pollen as they only occurred in **VCP2**.

4.3. Other Areas

4.3.1. Dr D’Olier (*pers. comm.* 2006) hypothesised that the banks on either flank of Barley Picle may represent the edges of a palaeochannel. The geophysical data indicate large sand banks seemingly of one general sediment type flanking a channel. The banks appear to lie conformably over older stratified sediments. There are no indications that the older sediments are banked on either side of the present-day channel. Also, there is no evidence of any cutting into the older sediments at the base of the channel. Although it is possible that the banks are composed of old material and represent the banks of a palaeochannel, based on the geophysics data it appears that the banks have accumulated on an old erosional surface and are younger sediments built up with an erosional channel formed much later.

4.3.2. The series of cut and fill sediments observed off the coast of Great Yarmouth on the Gorelston Road investigation line probably represent a cross section of a channel feature. This feature was not observed on the adjacent data in the Caister Road Channel and as such it was not possible to trace the channel eastwards. Unfortunately due to the shallow water over the sandbanks adjacent to Gorelston Road and Caister Road channels, intervening lines were not possible. There are three possible reasons for not tracing the channel feature on the data acquired in the Caister Road Channel:

- the channel may have been eroded away further from the coast leaving no trace of the feature;
- the channel follows a course directly north and was not observed on the adjacent seismic line;
- that this feature does not represent a channel, rather a smaller feature.

4.3.3. Due to its proximity to the current Yare River, it is possible that this channel or feature may form part of the Palaeo-Yare floodplain complex which was cut prior to the most recent marine transgression.

4.3.4. The aim of investigating these additional lines was to gain an overview of this area and identify any potential channels. However, it should be noted that small features may not be identified on the data and further investigation would be required for more detailed study of these features.

4.4. Conclusions

4.4.1. At Pakefield, sediment units were observed on the geophysical data that matched the extent and form of those described at the base of the cliff exposures (Parfitt *et al.* 2005). Vibrocore analyses enhanced the geophysical data interpretation and enabled a better understanding of the sediments and sediment deposition environments. This enabled correlation between onshore and offshore sediments. Although sediments of the Cromer Forest-bed Formation no longer exist offshore within the study area, older sediments interpreted as the Wroxham Crag Formation were identified. It was within the upper part of the Wroxham Crag Formation that worked flint was found onshore (Parfitt *et al.* 2005).

4.4.2. At Happisburgh, the survey was carried out further from the coast in deeper water than off Pakefield due to the presence of beach groynes that posed a risk to the equipment. Only sediments interpreted as older than those identified in the cliff exposures and on the foreshore were identified on the geophysical data. However, it is possible that younger sediments relating to the Cromer Forest-bed Formation observed on the foreshore and related early Middle Pleistocene sediments may be preserved closer to the shoreline.

4.4.3. The survey at Pakefield demonstrated that sediment units identified onshore can be traced offshore and that not all of these very early terrestrial sediments that are now in submerged areas have been removed by glacial processes and/or marine erosion.

4.4.4. Although a channel feature was found east-west across Barley Picle channel, there was no evidence to suggest that the sandbanks marking the edge of a channel relate to the edges of a palaeochannel. They are considered more likely to be banks of younger sediments that have accumulated on an old erosional surface and the Picle formed by later erosional processes. The channel feature at Barley Picle and further evidence of channel features close to the Great Yarmouth coast indicate a history of fluvial and glacio-fluvial activity off the coast of Norfolk throughout the Pleistocene.

4.4.5. The chirp sub-bottom profiling system was used throughout the surveys at Happisburgh and Pakefield. This proved a successful methodology in acquiring data nearshore, directly beneath the seabed. The chirp system generally produces a smaller seabed pulse compared to the boomer system. As such, less data is masked beneath the seabed pulse on chirp data, providing data within the first two metres below the seabed. Also, due to the higher frequency settings the chirp provides high resolution data within the first five metres sub-seabed; the layer of potential archaeological interest.

4.4.6. The geophysical and geotechnical methodologies used within this project demonstrated that fine-grained deposits can be identified and surveyed in nearshore areas, even where the deposits are close to the seabed, and that these can be related to the onshore cliff exposures.

4.4.7. Based on the survey results at Pakefield it is considered that the methodology employed during this survey could be used at similar sites along the coast.

4.4.8. This project has informed current knowledge on the survivability of deposits of possible archaeological interest, and has shown that it is possible to detect them using geophysical and vibrocoring equipment. Therefore, the project has confirmed that deposits of considerable archaeological interest may survive in areas adjacent to or within aggregate licence areas, and that they can be identified.

4.4.9. The results of the project will directly inform future marine aggregate dredging, both in terms of baseline knowledge of the historic environment in aggregate dredging areas, and the methodologies that can be used by industry to assess and mitigate any significant effects of dredging.

4.5. Recommendations for Further Work

4.5.1. Further work could include OSL dating of the additional cores, and palaeomagnetism and amino acid racemisation of molluscan material in order to provide a more definite chronological framework especially for the older sequences. Professor Jim Rose at Royal Holloway University, Egham, Surrey has agreed to undertake these dating procedures. The results of any dating should be integrated with the results of this report and inform any further environmental work.

4.5.2. A large seabed anomaly measuring 66 x 37 x 1.6m was identified off Happisburgh. The nature of the anomaly on the sidescan sonar data indicates that it is probably anthropogenic in origin, and the feature is located at the position of a seabed obstruction on Admiralty Chart 106 (2004). Further work would be required to ascertain the true nature of this anomaly.

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APPENDIX I: PAKEFIELD VIBROCORE LOGS

VCP1

Depth below seabed (m)	Depth below OD (m)	Description	Unit
0.00-0.83	5.83-6.66	2.5Y 4/3 Olive brown fine sand, in parts speckled with irregular patches of 2.5Y 2.5/1 black (organic?) clayey silt (big and dense patches at 0.04-0.07, 0.64-0.68, 0.75-0.79, 0.80-0.83, horizontal/angled bands at 0.22-0.65). No visible inclusions, very well sorted. Gradual boundary. **Recent shallow marine**.	D
0.83-1.08	6.66-6.91	2.5Y 4/2 Dark greyish brown fine to medium sand, slightly dark (organic? no silt) speckled especially at 0.98-1.02. No visible inclusions, very well sorted. Gradual boundary. **Recent shallow marine**.	
1.08-1.78	6.91-7.61	5Y 4/2 Olive grey fine sand, no visible inclusions, very well sorted, densely laminated with bands of 2.5Y 2.5/1 black sandy silt at 1.08-1.14 and 1.18-1.23 (1.08-1.12: *c.* 3mm wide, 5-10mm distance, especially dense from 1.12 on, only patches of sand left there in between). Patch of 10YR 5/8 yellowish brown sand at 1.23-1.24 (15mm) and 3 sharply distinguished 10YR 5/8 yellowish brown sand bands at 1.28-1.29, only 1.29 covering the whole width (*c.* 2mm wide, 2mm distance), in between them is dark sand. Sharply distinguished layers of 2.5Y 3/1 very dark grey clayey silt from 1.29 downwards, at 1.29-1.37, 1.43-1.57, 1.62, 1.65-1.78 (2-10mm wide, distance 2-10mm), especially dense at 1.51-1.54, 1.73-1.78 (only very thin sand layers left here). Lost section at 1.14-1.18. Abrupt boundary. **Recent shallow marine**.	C
1.78-2.06	7.61-7.89	2.5Y 4/2 Dark greyish brown medium to coarse sand with occasional shell fragments and rare subangular gravel inclusions (<10mm), well sorted, layered with. Broken bands of 2.5Y 3/1 very dark grey sandy clayey silt with occasional shell inclusions (<12mm) at 1.79-1.82, 1.84, 1.87-1.90, 1.92-1.93, 1.95, 1.97-2.00. Dense band of 2.5Y 3/1 very dark grey clayey silt at 1.00-1.04 with no visible inclusions. Abrupt boundary. **Wroxham Crag Formation**.	Biv
2.06-2.29	7.89-8.12	5Y 4/2 Dark greyish brown coarse sand, moderately sorted, no visible inclusions apart from a poorly sorted gravel bed at 2.10-2.16, gravel subrounded to subangular (<10mm). **Transition**.	Bii
2.29-3.04	8.12-8.87	5Y 4/1 Dark grey clay with very thin and dense brighter sandy clay laminations at 2.57-2.69 (*c.* 1-5mm wide, 1-5mm distance) and less dense, broken laminations at 2.45-2.47, 2.51-2.53. Bright sandy wedge at 2.31-2.33. Lost section at 2.99-3.04. **Estuarine alluvium, early Pleistocene**.	Aii

VCP2

Depth below seabed (m)	Depth below OD (m)	Description	Unit
0.00-0.33	5.06-5.39	2.5Y 5/4 Light olive brown silty sand (fm). Soft. Occasional clayey silty lenses (1-2mm) 0.00-0.08. Small razor clam 0.08, 0.20. Frequent broken shell. Fine sand inc. ?organics. Sea urchin spines 0.28m. Sorted. Abrupt/wavy boundary. **Recent shallow marine**.	D
0.33-0.41	5.39-5.47	2.5Y 5/2 Greyish brown very silty sand (f). Silt includes degraded organics and occasional small angular (<4mm) flint. Soft. Poorly sorted ?burrow. Abrupt boundary. **Recent shallow marine**.	

Depth below seabed (m)	Depth below OD (m)	Description	Unit
0.41-0.61	5.47-5.67	2.5Y 4/1 Dark grey sand (fm). Moderate broken shell. Occasional organics. Coarser sand (0.48-0.50). Sorted. One ?FeO stained subrounded sandstone (5mm) @ 0.53m edge of core (?intrusive). Abrupt boundary. **Recent shallow marine**.	
0.61-0.73	5.67-5.79	(0.61-0.63) 2.5Y Grey. (0.63-0.73) 2.5Y 6/3 Light yellowish brown sand (mc). Soft. Well sorted. Occasional (?FeO stained) bands 0.63-0.73m. Abrupt boundary. Colour change due possibly to water content? **Recent shallow marine**.	C
0.73-1.10	5.79-6.16	2.5Y 5/1 Grey sand (fm). Some banding (light grey sand (mc)/dark grey sand (fm) from 0.90-1.08. 0.73-0.88 sand predominantly fine. 0.88-1.10 sand predominantly medium. Fining up. Well sorted. Soft to firm. Abrupt boundary. **Recent shallow marine**.	
1.10-1.28	6.16-6.34	2.5Y 6/3 Light Yellowish brown gravely sand(mc). Moderate gravel 1.10-1.18 rounded – subrounded (5-35mm). 1.18-1.28 sand (m) some feint banding. Coarsening up. Poorly sorted at top (-1.18) becoming well sorted. Loose. Gradual boundary. **Wroxham Crag Formation**.	
1.28-1.95	6.34-7.01	2.5Y 6/1 Clayey silty sand (fm). Bands of lighter/darker sand (*c.* 40mm). Well sorted. Clayey silt bands (1.375, 193-195). Clayey silt lumps (80mm) 1.76-1.90. Some coarse sand 0.86-0.91. Generally well sorted. 1.375 clayey silty band. Abrupt boundary. **Wroxham Crag Formation**.	Bii
1.95-2.10	7.01-7.16	2.5Y 6/2 Light brownish grey gravelly sand (mc). Moderate flint in band from 1.98-2.05, brown/black subrounded-rounded 5-10mm diam. Sand appears to have a high quartz content. Gradual boundary. **?Early Pleistocene.**	
2.10-2.15	7.16-7.21	2.5Y 5/1 Grey sand (f). Well sorted. Abrupt boundary. **?Early Pleistocene.**	
2.15-2.17	7.21-7.23	2.5Y4/1 Dark grey clayey silt. Well sorted. Compact. Occasional black flecks. Abrupt boundary. **Estuarine alluvium, early Pleistocene.**	
2.17-2.23	7.23-7.29	2.5Y/1 Grey sand (m). well sorted including lumps of silty clay (as above). Abrupt boundary. **Early Pleistocene.**	
2.23-2.32	7.29-7.38	2.5Y 4/1 Dark grey gravelly sand (mc). Gravel small (<15mm) subrounded-rounded sorted flint (80%) and quartz (20%). Moderate – frequent organics (coalified wood from below). Sand coarsening up with high quartz content. **Early Pleistocene.**	Bi
2.32-2.36	7.38-7.42	2.5Y 2.5/1 Black sandy (fm) wood. Wood is black, occasionally coalified (?lignite). Sand is predominantly medium with a high quartz content. Layering of the wood can be seen clearly especially at the base 2.35-2.36. Abrupt boundary. **Early Pleistocene.**	
2.36-2.43	7.42-7.49	2.5Y 5/1 Grey sand (fm). Fining upwards with clayey silt lenses @ 2.37. Gradual boundary. **Early Pleistocene.**	
2.43-3.16	7.49-8.22	2.5Y 5/3 Light olive brown sand (mc). Soft. Some banding (FeO stained)/ extra coarse sand bands 2.43-2.61 including small subangular-subrounded quartz/flint. 2.90-3.16 increasing gravel inclusions – slightly sorted rounded-subangular 5-15mm flint/quartz. Flint is generally black/brown. Abrupt boundary. **Early Pleistocene.**	Ai
3.16-3.62	8.22-8.68	2.5Y 5/2 Greyish brown sand (fm). Laminar 3.17-3.50. Very well sorted. Slightly compact. Very occasional (1) flint – subrounded (15mm) @3.46m. **Early Pleistocene.**	

VCP3

Depth below seabed (m)	Depth below OD (m)	Description	Unit
0.00-0.03	6.02-6.05	Missing	
0.03-0.51	6.05-6.53	2.5Y 5/2 Greyish brown sandy silt/silty sand (f). Soft. Sorted. Silty bands 0.03-0.09, 0.15-0.26, 0.32-0.48. Occasional feint horizontal lenses/bands of fine sand within silty bands. Moderate finely crushed shell. Abrupt boundary. **Recent shallow marine**.	D
0.51-1.82	6.53-7.84	2.5Y 6/3 Light yellowish brown silty sand (fm). Very occasional (1 @ 0.71) rounded flint (10mm). Well sorted. Some siltier/darker (2.5Y 4/2 dark greyish brown sandy silt) patches (0.75-0.80) and laminations 1.15,1.19,1.20, 1.54, 1.56, 1.61, 1.67 (5-15mm). Broken bivalve @ 1.22. Moderate crushed shell becoming more frequent from 1.30 onwards. Becoming siltier towards base (1.31-1.45 mostly silt). Very frequent crushed shell @ 1.40, 1.68-1.74, 1.74-1.82. ?Organic frags 1.68-1.74. Abrupt boundary. **Recent shallow marine**.	C
1.82-1.90	7.84-7.92	2.5Y 3/2 Very dark greyish brown silty sandy (fm) gravel. Frequent broken shell (bivalves.) Gravel small-medium (<25mm) subrounded-subangular poorly sorted flint (70%) quartz (30%). Frequent degraded organics (<5mm). Compact. Abrupt boundary. **Wroxham Crag Formation**.	Biii
1.90-2.17	7.92-8.19	2.5Y 6/1 Grey sand (m). Moderate shell inclusions (2.12-2.14) broken bivalves. Gradual boundary. **Wroxham Crag Formation**.	Bii
2.17-2.26	8.19-8.28	2.5Y 4/1 Dark grey silty gravelly sand (mc). Very frequent broken bivalves. Occasional lumps of clayey silt (<15mm). Sorted. Gravel (<10mm) predominantly small subrounded-angular quartz and (black) flint. Fairly compact. Occasional ?organics, small hard (?lignite). Sorted. Very abrupt boundary. **Wroxham Crag Formation**.	Bi
2.26-3.74	8.28-9.76	2.5Y 4/1 Dark grey/2.5Y 3/1 Very dark grey sandy (f) (silty) clay. Very stiff. Well sorted.Fine sand wavy laminae inc probable flood couplets throughout. Some darker (<0.5mm) 'organic' bands. Fine sand bands increasing from 2.56. Fining up. 3.56-3.67 mostly fine sand laminae with darker/lighter bedding visible. Abrupt boundary. **Estuarine alluvium**. **Early Pleistocene.**	Aii
3.74-4.32	9.76-10.34	2.5Y 3/1 Grey silty clayey sand (m). Softer than above. Moderate to frequent broken ?bivalve shell. Occasional small (<10mm) subrounded black flint. Sandy (f) clayey silt bands 3.82-3.84, 4.14-4.32. Brown ?FeO staining (2mm) @ 3.74. **Early Pleistocene.**	Ai

APPENDIX II: POLLEN ANALYSIS

Pollen analysis of the early Pleistocene sediments in the Bytham Channel, Pakefield, Norfolk

Dr. Rob Scaife
School of Geography
University of Southampton
Highfield
Southampton
SO17 1BJ

1.) Introduction

Pollen analysis has been carried out on one of the two vibrocores obtained from the Bytham Channel offshore. A basal sequence of humified organics contains a temperate flora whilst overlying minerogenic sediments appear to have a flora of Boreal affinity. Comparable pollen data come from the definitive work of R.G. West on the coastal sites of Norfolk (West 1980) and the more recent studies of off-shore sediments in the North Sea Basin (e.g. Ekman 1998). Dating of the Pakefield sequence is not possible from pollen alone and will rely on OSL determinations.

2.) Pollen analysis

Sediment sub-samples of 2ml volume were taken from the vibrocores were prepared using standard techniques for the concentration of sub-fossil pollen and spores (Moore and Webb 1978; Moore *et al.* 1992). Micromesh sieving (10u) was also used to aid with removal of the clay fraction where present in these sediments. A pollen sum of up to 400 grains per sample level was counted except for the uppermost sample at 1.40m where preservation was poor and a count of 100 only was feasible. Other, miscellaneous microfossils including algal *Pediastrum* and pre-Quaternary palynomorphs were also recorded. Data are presented in pollen diagram form plotted using Tilia and Tilia Graph (see figure). Percentages have been calculated as follows:

Sum = % total dry land pollen (tdlp).
Marsh/aquatic = % tdlp + sum of marsh/aquatics.
Spores = % tdlp + sum of spores.
Misc. = % tdlp + sum of misc. taxa.

Taxonomy, in general, follows that of Moore and Webb (1978) modified according to Bennett *et al.* (1994) for pollen types and Stace (1992) for plant descriptions. These procedures were carried out in the Palaeoecology Laboratory of the School of Geography, University of Southampton.

3.) The Pollen Data

Pollen was, in general, well preserved although not abundant in any sample. Absolute pollen frequencies were in the order of 10,000 grains/ml. Only in the uppermost sample were numbers extremely small. There are clear differences in the pollen spectra between a basal organic unit and overlying more mineral sediment. Two local pollen assemblages zones have thus been defined and which are characterised as follows.

Zone 1: 2.34m. Alnus-Pteridophytes. This single basal sample differs from all others being humified peat with little minerogenic component. *Alnus* is dominant (78%) with small numbers of *Betula*, *Quercus* (3%), *Ilex* and *Pinus*. There are few herbs with Poaceae (10%) most important. Marsh taxa include Cyperaceae, *Typha latifolia* and *Osmunda*. Spores are dominant with substantial numbers of monolete forms (*Dryopteris* type; 75% Sum+Spores) and *Osmunda* (15% sum + spores).

Zone 2: 2.24-1.40m. Pinus-Ericaceae. These levels form the larger part of the pollen sequence and comprise minerogenic sediments of varying humicity, size and texture. Pollen samples come from those finer grained sediments which contain pollen and spores. Although spanning 80cm of sediment, the pollen content is largely homogeneous throughout with only minor percentage changes. Trees, dwarf shrubs/Ericales and herbs all form important constituents of the pollen assemblages.

Trees are dominated by *Pinus* (to 43%) with small numbers of *Betula*, *Picea* (to 4% at 216cm), possible *Abies*, Cuppressaceae (?*Juniperus*) and *Salix*. *Quercus, Alnus* and *Ilex* are also present and may be derived from earlier sediments (*Alnus* from the lower peat ?). Dwarf shrubs are important being dominated by *Erica* spp. (to 38% at 196cm) with smaller numbers of *Empetrum* (1-2%), *Calluna*, and *Vaccinium*. There is moderately diverse range of herbs with Poaceae dominant (to 36% at 2.16m averaging 20-30%). There are minor peaks of *Artemisia* (5%) and Lactucoideae (3%) at the base of the zone and consistent but small occurrences of Chenopodiaceae. Marsh taxa remain as previously with Cyperaceae (3%) and occasional occurrences of *Typha angustifolia* type, *Nymphaea* and *Potamogeton* type. The dominance of spores in zone 1 is much diminished (monolete forms to 20%). In addition are sporadic occurrences of *Selaginella selaginoides, Lycopodium* sp., *Pteridium* aquilinum and *Botrychium lunaria*. *Sphagnum* becomes more important (6%). Pre-Quaternary palynomorphs are important in these largely mineral sediments peaking to 60% at 1.72m. Algal *Pediastrum* and dinoflagellates are present throughout.

4.) Discussion

It is clear that there are two distinct environments represented in this profile which are separated by a hiatus. These contrasting data comprise a lower (pollen) zone which is of temperate affinity and the majority of the profile (zone 2) which is displays a colder, Boreal habitat.

The lower pollen zone (1), albeit a single sample, comes from a thin basal organic horizon which rests on basal Norwich Crag Formation. This pollen assemblage demonstrates that an alder dominated habitat existed on-site. Apart from the substantial numbers of alder pollen this is also suggested by clusters (broken anthers?) of alder pollen which are also present. The presence of Osmunda (probably *O. regalis*: Royal fern) and Cyperaceae suggest that the habitat was a damp fen rather than a fully aquatic environment. The substantial representation of spores is probably a result of differential preservation of autochthonous marsh fern, *Thelypteris palustris* (a single definite record is present) in these highly humified peats.

The dominance of on-site alder has probably had a masking effect on the pollen with resulting poor representation of the non-wetland component. Whilst it is normal to exclude *Alnus* from the pollen sum (Janssen 1969), pollen numbers from allochthonous sources was very small negating valid counts. However, some indications as to the character of the woodland of surrounding areas exist with small numbers of birch, oak, holly and cf. hornbeam. The overall assemblage of deciduous woodland (including alder) suggest a temperate stage of an interglacial period.

Above the basal organic horizon there is a marked change in the pollen and inferred vegetation to one of Boreal affinity (Zone 2). The transition is sharp and it is likely that there was a substantial hiatus in the sedimentation. Whilst the lower organic unit (Zone 1) was of fen character, it is possible that the start of mineral sedimentation was initiated by a positive eustatic change which saw onset of brackish or saline conditions. This is evidenced by the character of the sediments (sand) and other microfossil evidence (? Foraminifera). Palynologically, however, there is only tentative evidence with occasional occurrences of possible halophytes such as Chenopodiaceae, *Plantago maritima* type and dinoflagellates. It is unfortunate that diatoms are not preserved in these sediments. There is, however, evidence of freshwater with *Pediastrum* and small numbers of aquatic and marsh taxa.

The taphonomy of the pollen assemblages of zone 2 is more complex than the for the basal organic component since here, there are the added components of reworked pollen and spores, the greater likelihood of fluvial transport from long distances and the differential flotation effects of pollen (esp. pine). This is indicated by the substantial numbers of pre-Quaternary palynomorphs and also the possibility pollen of thermophiles may have been reworked from the earlier temperate sediments.

It has been noted that in North Sea pollen assemblages presence of pre-Quaternary palynomorphs and only small numbers of thermophiles is indicative of sedimentation under a cold or glacial climate (Ekman 1998) with the former also used as a measure of reworked material. Here, there is strong boreal woodland component with *Pinus* dominant and small, but never the less, important numbers of *Picea* an *Abies*. These assemblages suggest a boreal woodland environment which may be of pre-temperate or post-temperate zonation (Turner and West 1968). A post temperate zone may be postulated from the underlying temperate peat of lpaz 1. However, this depends on the length of the stratigraphical hiatus and any intervening erosive events. Throughout the upper/ mineral sediments there is a constant occurrence of thermophiles which include *Alnus, Quercus, Carpinus* and *Ilex* and whilst it is possible that these contemporaneous, it is more probable that these are reworked from earlier sediments, possibly the basal organics.

Ericaceae are an especially important component of this Boreal zone. These comprise largely *Erica* with small numbers of *Empetrum, Vaccinium* and *Calluna*. These along with *Sphagnum, Lycopodium* (sp. indet) and *Selaginella selaginoides* are indicative of acid heathland also commensurate with what would have been acidic soils associated with the predominant coniferous woodland.

5.) Preliminary comments on Dating

Pollen was for a long time the primary means of dating of interglacial sediments by comparison of one site with other known data, often associated with the long stratigraphical sequences such as Ludham (West 1956), the interglacial type sequences (Cromer, Hoxne, Marks Tay and Bobbitshole) and archaeological implications. This has been superceded by OSL and amino acid dating and as such, data from Pakefield will hopefully put the sequence into developing model of Lower Pleistocene stratigraphy.

It has been suggested that part of the Pakefield sequence might be of Cromerian Complex date. This may include, therefore, not only the Cromerian, but earlier warm and cold stages which are still not fully understood or have been correlated with the ocean sediment and ice core records. Palynologically, the data obtained could indeed be of Cromerian Complex date. The pollen taxa compare with those data obtained from the other coastal sites of Cromer and Pakefield (West 1986). Ekman (1998) provides the best comparison for possible Cromerian assemblages by providing a long stratigraphical profile from the central North Sea basin. Whilst this work also has dating problems it never the less provides useful framework with which to compare these Pakefield results. West (1980) has defined in detail, the biostratigraphy of the principal Cromerian interglacial (1980, 20) based on East Anglian coastal sites of West Runton especially and also Pakefield, Corton and Sidestrand etc. Of these, a late Cromerian (Cr. IVa) is most applicable for both Pakefield zones discussed here. That is, containing *Pinus*, *Alnus, Picea* and *Betula*. Comparison with Ekman's diagram shows some correlation with pollen zones 5 to 8. That is, with *Alnus* which then declines to low levels but is superceded in the profile by conifers (dominant *Pinus* with *Picea* and Abies also with Ericales). It can also be noted that Ekman also specifically discusses the presence of *Osmunda regalis* in this part of his Devils Hole sequence. This does not, however, conclusively date the sequence to the Cromerian since there are also palynological affinities with the later part of the Pastonian sequence (Pastonian IVa) at Beeston (West 1980, 40-43) and the, as yet undated but probably Cromerian Complex, site at Norton Subcourse (Scaife in prep.). However, no Plio-Pleistocene exotic indicator taxa were observed in this Pakefield sequence. West's (1980) analysis of Pakefield identified some pre-Pastonian sediments containing *Pinus* and Ericales (defined as a pollen assemblage zone) with smaller numbers of *Alnus, Picea* and *Betula*. This was correlated with the upper levels of the Ludham borehole (Lu 4c; West 1956). This assemblage appears, in fact, to be more analogous to the offshore Pakefield sequence than are the pollen assemblages at Pakefield which are attributed to the overlying Pastonian and Cromerian sequences. It is anticipated that OSL dating may provide a clearer result by correlating this profile with the upper Ludham sequence, the Pastonian, Cromerian Complex or Cromerian *sensu stricta*.

5.) Summary and Conclusions

* A basal organic unit comprising humified peat (zone 1) which rests on Norwich Crag accumulated in a damp alder fen environment. *Alnus* was dominant with a ground flora of marsh and Royal fern and sedges.

* Evidence of surrounding woodland during this initial phase is poor. However, there are some indications that this comprised thermophiles including *Quercus, Ilex,* and *Carpinus*.

* The basal organic sequence is of temperate affinity.

* Overlying mineral sediments rest unconformably on the basal organics and a substantial hiatus is suspected.

* Pollen spectra in zone 2 differ markedly from the temperate elements of zone 1. Boreal, coniferous woodland is dominant with *Pinus* and some *Picea* and *Abies*. Ericaceous heath was also important on acidic soils.

* This Boreal phase is of either pre- or post temperate affinity or from an interstadial period.

* Based on stratigraphy it has been suggested that this sediment sequence falls within the Cromerian Complex. This may be pre Cromerian *sensu-stricto* or part of the Cromerian itself. If the latter, late Cromerian (Cr IV). However, there are also similarities with the Pastonian.

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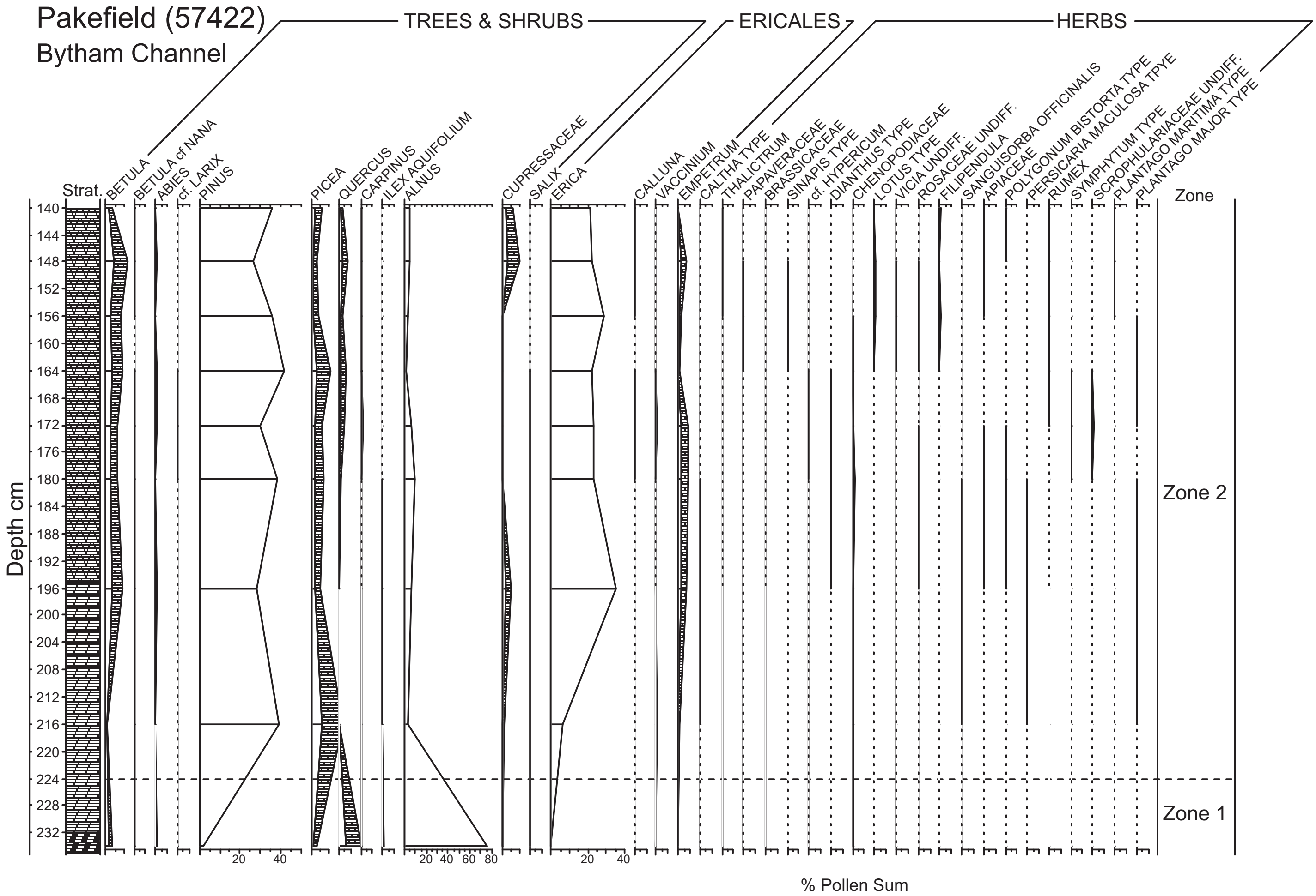
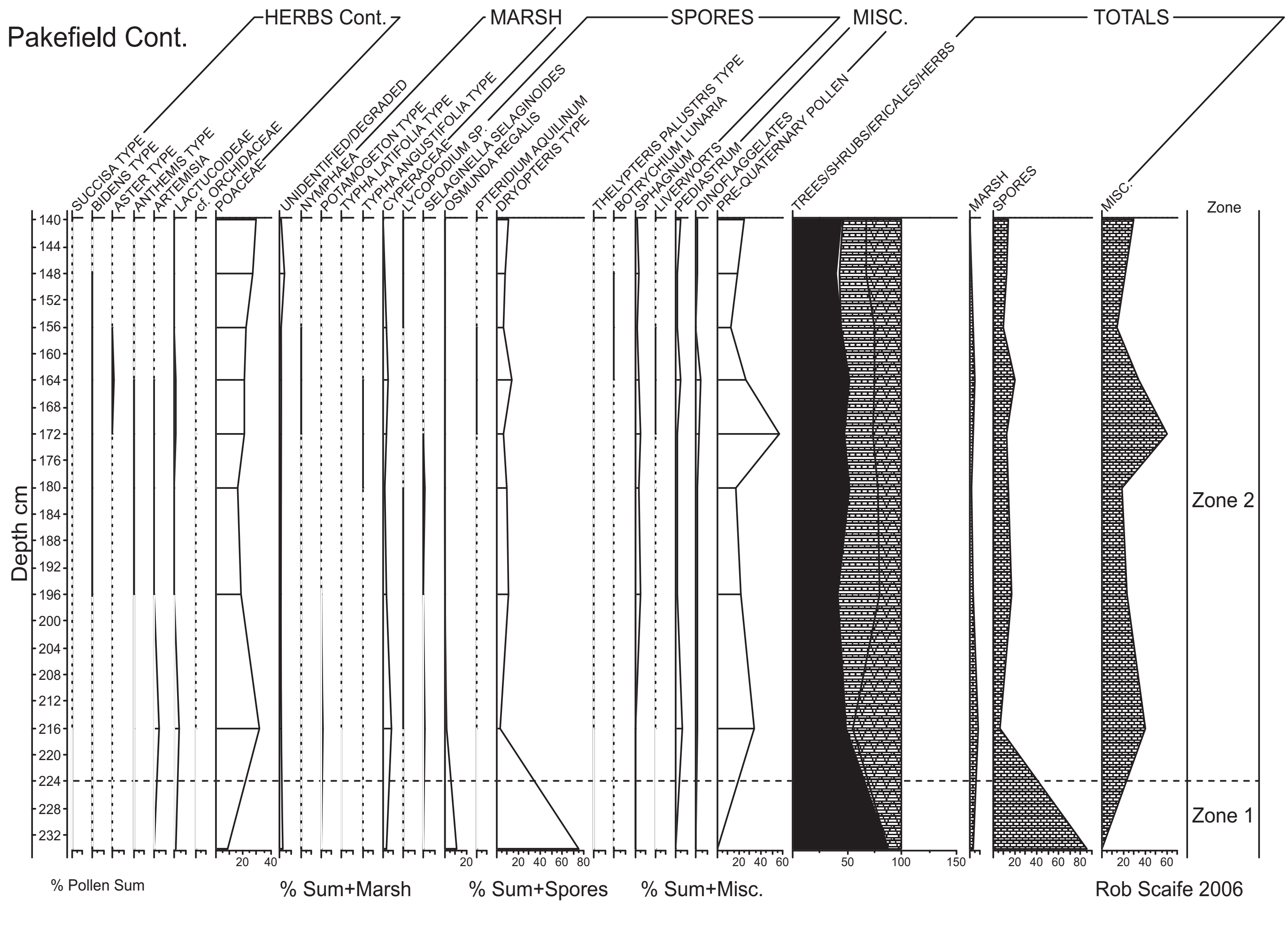

Pakefield (57422)
Bytham Channel
TREES & SHRUBS
ERICALES
HERBS
Strat.
BETULA
BETULA cf NANA
ABIES
cf. LARIX
PINUS
PICEA
QUERCUS
CARPINUS
ILEX AQUIFOLIUM
ALNUS
CUPRESSACEAE
SALIX
ERICA
CALLUNA
VACCINIUM
EMPETRUM
CALTHA TYPE
THALICTRUM
PAPAVERACEAE
BRASSICACEAE
SINAPIS TYPE
cf. HYPERICUM
DIANTHUS TYPE
CHENOPODIACEAE
LOTUS TYPE
VICIA UNDIFF.
ROSACEAE UNDIFF.
FILIPENDULA
SANGUISORBA OFFICINALIS
APIACEAE
POLYGONUM BISTORTA TYPE
PERSICARIA MACULOSA TPYE
RUMEX
SYMPHYTUM TYPE
SCROPHULARIACEAE UNDIFF.
PLANTAGO MARITIMA TYPE
PLANTAGO MAJOR TYPE
Zone
Depth cm
Zone 2
Zone 1
% Pollen Sum


Pakefield Cont.
HERBS Cont.
MARSH
SPORES
MISC.
TOTALS
SUCCISA TYPE
BIDENS TYPE
ASTER TYPE
ANTHEMIS TYPE
ARTEMISIA
LACTUCOIDEAE
cf. ORCHIDACEAE
POACEAE
UNIDENTIFIED/DEGRADED
NYMPHAEA
POTAMOGETON TYPE
TYPHA LATIFOLIA TYPE
TYPHA ANGUSTIFOLIA TYPE
CYPERACEAE
LYCOPODIUM SP.
SELAGINELLA SELAGINOIDES
OSMUNDA REGALIS
PTERIDIUM AQUILINUM
DRYOPTERIS TYPE
THELYPTERIS PALUSTRIS TYPE
BOTRYCHIUM LUNARIA
SPHAGNUM
LIVERWORTS
PEDIASTRUM
DINOFLAGGELATES
PRE-QUATERNARY POLLEN
TREES/SHRUBS/ERICALES/HERBS
MARSH
SPORES
MISC.
Zone
Depth cm
Zone 2
Zone 1
% Pollen Sum
% Sum+Marsh
% Sum+Spores
% Sum+Misc.
Rob Scaife 2006

APPENDIX III: DIATOM ASSESSMENT

Diatom analysis from Pakefield, Bytham Channel offshore (57422)

Nigel Cameron
Environmental Change Research Centre
Department of Geography
University College London
Pearson Building
Gower Street
London WC1E 6BT

Introduction

Recent work has demonstrated the archaeological significance of struck flakes dated to the Middle Pleistocene from the Bytham Channel (Mike Allen pers. comm.; Lee *et al.* 2006; Parffitt *et al.* 2006.). In the assessment of these sediments, diatoms were found to be absent from six samples (Rob Scaife). However, in the present study further sediments are to be assessed/analysed for diatoms.

Methods

Diatom preparation followed standard techniques: the oxidation of organic sediment, removal of carbonate and clay, concentration of diatom valves and washing with distilled water. Two coverslips, each of a different concentration of the cleaned solution, were prepared from each sample and fixed in Naphrax, a mountant of a suitable refractive index for diatom microscopy. Further details of sediment preparation methods can be found at: (http://www.geog.ucl.ac.uk/~jhope/lab/sedi.htm). A large area of the coverslips on each slide was scanned for diatoms at magnifications of x400 and x1000 under phase contrast illumination.

Results & Discussion

Initial diatom assessment by Rob Scaife of six samples from two cores showed diatoms to be absent. In vibrocore VCP3 samples at 2.28, 3.00, 3.72 and 4.20m proved not to contain diatoms. In vibrocore VCP2 samples at 1.72m and 2.16m proved not to contain diatoms.

The results of this diatom assessment of further samples from vibrocore VC-P2 are summarised in Table 1.

Sample depth (m)	*Deposit*	*Diatoms present*	*Diatom concentration*	*Quality of preservation*	*Diversity*	*Assemblage type*	*Potential for % count*
1.32	?Interglacial deposits	absent	-	-	-	(see below)	none
1.56		absent	-	-	-	-	none
1.88		absent	-	-	-	-	none
2.34	?Norwich Crag	absent	-	-	-	-	none

Table 1. Summary of diatom evaluation results for Pakefield, Bytham Channel offshore (57422) VC-P2.

Diatoms are absent from all four sediment samples from VC-P2, with the exception of a single, very small indeterminate fragment found at 1.32m. Given the ubiquity of diatoms in natural water bodies, the absence of their remains from water-lain sediments is likely to be the result of taphonomic processes. In particular this is often the result of silica dissolution caused by factors such as high sediment alkalinity, very high acidity, the undersaturation of sediment pore water with dissolved silica, cycles of prolonged drying and rehydration, or exposure of sediment to the air (e.g. Flower 1993; Ryves *et al.* 2001). However, these factors do not preclude the preservation of diatoms. Diatom valves are for example well preserved in permanently dried material in sediment archives and in the sediments of acidified and naturally highly alkaline lakes. Unfortunately because of the complete absence of diatoms here it is not possible to comment on the nature of sediment deposition or changes in water quality.

Conclusions

Diatoms are absent from all four samples examined from VC-P2 at the Pakefield, Bytham Channel offshore (57422) site.

It appears that the diatom assemblages of the four samples have been lost as a result of silica dissolution. This has led to complete loss of the diatom record with only a single, small indeterminate diatom fragment present in one sample.

There is no further potential for diatom analysis of these samples.

Acknowledgements

Thanks to Mike Allen of Wessex Archaeology for the samples for diatom analysis, details of the VC-P2 sequence and publications associated with the site.

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APPENDIX IV: OSTRACOD ASSESSMENT

Jack Russell
Wessex Archaeology

Introduction
Seven sub-samples were assessed for the presence and preservation of ostracods. Three samples from vibrocore **VCP2** and four from vibrocore **VCP3**. The sediments are thought to comprise sands, silts and clays thought to be part of the Bytham River system.

Method
Sediment was wet sieved through a 63µm sieve. The sediment was dried and sieved through 500µm, 250µm, 125µm sieves. Ostracods were picked out under 10-60x magnification and transmitted and incident light using a Meiji EMT microscope.

Results
One broken and unidentifiable ostracod was recovered from the sample at 3.72m in vibrocore **VCP3**. Three samples from vibrocore **VCP2** at 1.72, 2.16 and 2.34m produced no ostracods. The samples at 2.28, 3.00 and 4.20m in vibrocore **VCP3** produced no ostracods.

Discussion/Further work
No further work is recommended for the assessed sequences.

APPENDIX V: FORAMINIFERA ASSESSMENT

Jack Russell
Wessex Archaeology

Introduction

Seven sub-samples were assessed for the presence and preservation of foraminifera. The assessment was also conducted in order to assess the possibility of biostratigraphic correlation between vibrocores **VCP2** and **VCP3** and to assess the environmental and chronological potential of any Pleistocene foraminifera recovered. Three samples from vibrocore **VCP2** and four from vibrocore **VCP3** were. The sediments are thought to comprise sands, silts and clays thought to be part of the Bytham River system. Foraminifera were present in four of the seven samples. Dr John Whittaker aided with the identifications of this material.

Method

Sediment was wet sieved through a 63µm sieve. The sediment was dried and sieved through 500µm, 250µm, 125µm sieves. Foraminifera were picked out under 10-60x magnification and transmitted and incident light using a Meiji EMT microscope. Where possible fifty specimens per sample were picked out and kept in card slides. Identification and interpretation of ecology follows Funnel (1989) and Murray (1973, 1991).

Results

Foraminifera were not present in any of the three samples from vibrocore **VCP2**. Four samples from vibrocore **VCP3** produced foraminifera. In **VCP3** the laminated silty clay sequence described as Unit Aii and silty clayey sand Unit Ai both produced foraminifera. Foraminifera per sample in vibrocore **VCP3** is summarised in **Table 1**. Abundance of foraminifera was moderate to high in those samples containing foraminifera, preservation was moderate.

VCP2 (3 samples):
At 1.72, 2.16 and 2.34m no foraminifera were recovered.

VCP3 (4 samples)
At 2.28m abundance of foraminifera was low to moderate with 35 specimens recovered. Preservation was moderate The assemblage comprised *Elphidium arcticum* and *Elphidiellla hannai.* At 3.00m abundance of foraminifera was very low with 7 specimens recovered. The assemblage contained *Elphidium* sp., *Elphidiella hannai* and *Rosalina* sp..
At 3.72m abundance of foraminifera was low to moderate with 34 specimens recovered. Preservation was moderate. The assemblage was dominated by *Elphidium arcticum* and *Elphidiella hannai. Elphidium cf. bartletti* was also present. At 4.20m abundance of foraminifera was moderate with 70 specimens recovered. The assemblage was dominated by *Elphidium arcticum* and *Elphidiella hannai*.

Discussion

Biostratigraphic correlation between the **VCP2** and **VCP3** could not be achieved due to a lack of foraminifera from **VCP2**. This could be due to localised preservational conditions and therefore correlation between the two cores using foraminifera is inconclusive.

The assemblages recovered from **VCP3** are low diversity and dominated by *Elphidium arcticum* and *Elphidiella hannai*. *Elphidium* cf. *bartletti* was also present. The samples are all similar in diversity of taxa although vary in abundance. This low diversity assemblage of *Elphidium* and *Elphidiella* including *Elphidium* cf. *bartletti* and notably lacking in *Ammonia* is indicative of cold, estuarine conditions.

Similar assemblages from shallow marine and estuarine sediments forming part of the Norwich Crag Formation were described by Funnell (1961). These sediments are thought to date from the pre-Pastonian/early Pleistocene period (Allen and Keen 2000). *Elphidiella hannai* is common in littoral and inner sublittoral environments of the Early Pleistocene of the North Sea Basin and is not known from the British Isles after the Anglian (Funnel 1989).

Further work

Further samples from core **VCP3** could be investigated to identify any notable changes within the sequence. Unit B would appear to contain the most archaeologically interesting sequence (the lower part of the Bytham river). One sample from this sequence has been assessed from **VCP2** (at 1.72m). It is considered that further samples should be assessed for foraminifera from this Unit in vibrocore **VCP3**.

It would appear that the assessed sediments producing foraminifera (Units Aii and Ai: samples at 2.28, 3.00, 3.72 and 4.20m) in vibrocore **VCP3** are considerably older (possibly *c.*1 million years) than the implementiferous sediments described onshore (Parfitt *et al.* 2005). However further work on these foraminifera and sediments would enhance the understanding of the environment and chronology of the early Pleistocene period.

Table 1: Presence/absence of foraminifera in vibrocore VCP3

VCP3 Depth below seabed in m	***Elphidiella hannai***	***Elphidium* sp.**	***Elphidium arcticum***	***Elphidium c.f. bartletti***	***Rosalina* sp.**
2.28	x	-	x	-	-
3.00	x	x	-	-	x
3.72	x	-	x	x	-
4.20	x	-	x	-	-

Present - x

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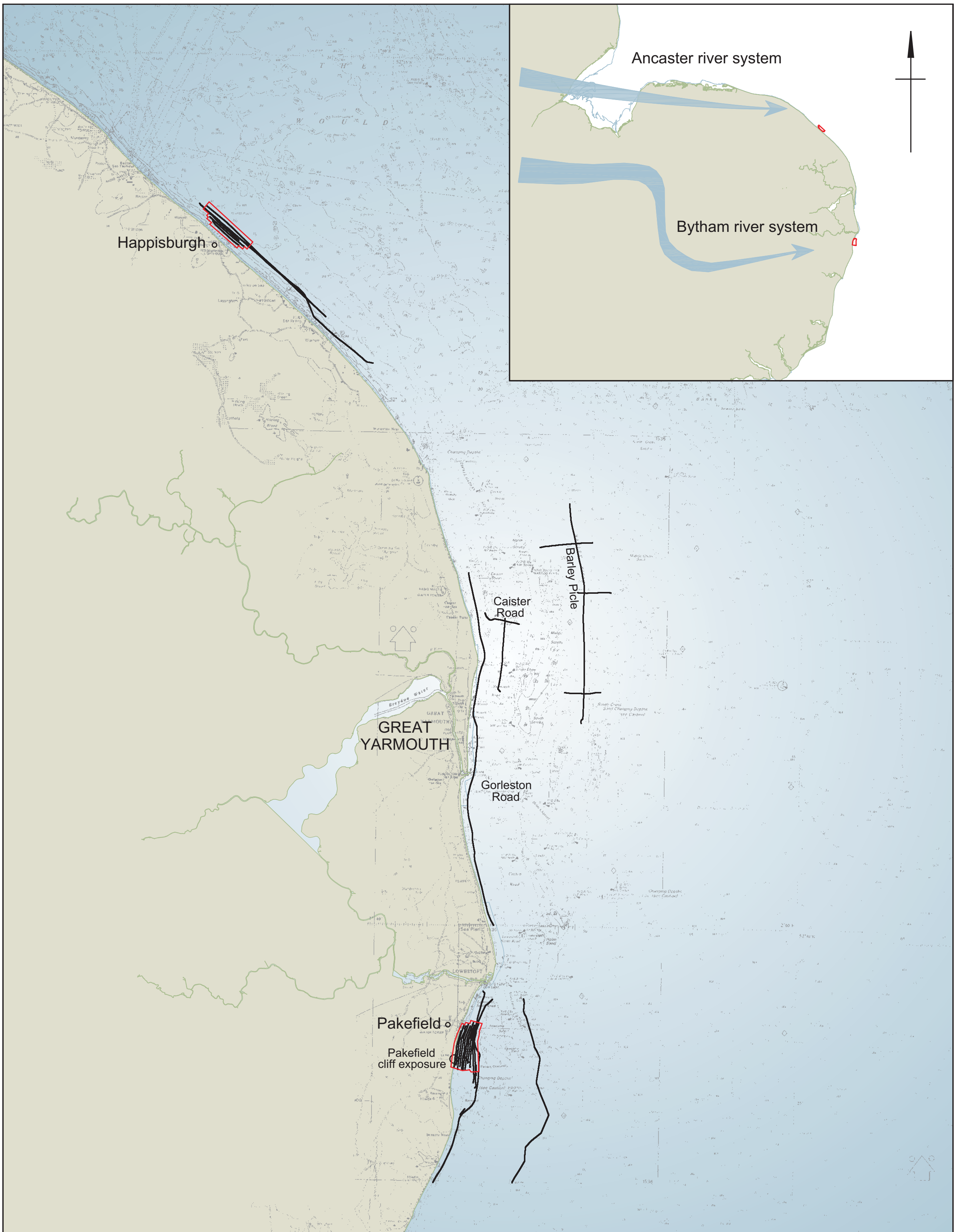

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Location map and survey lines

Figure VII.1

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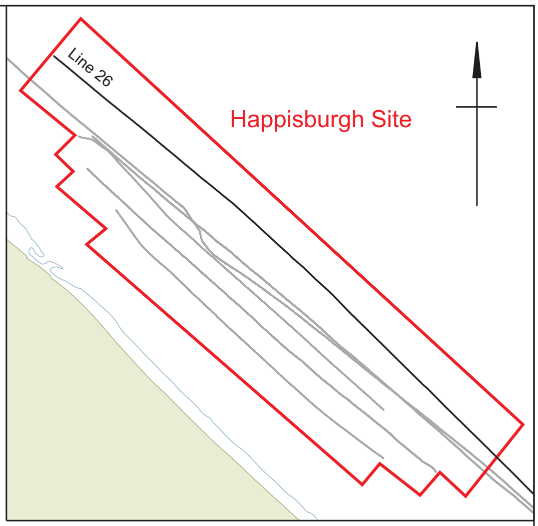
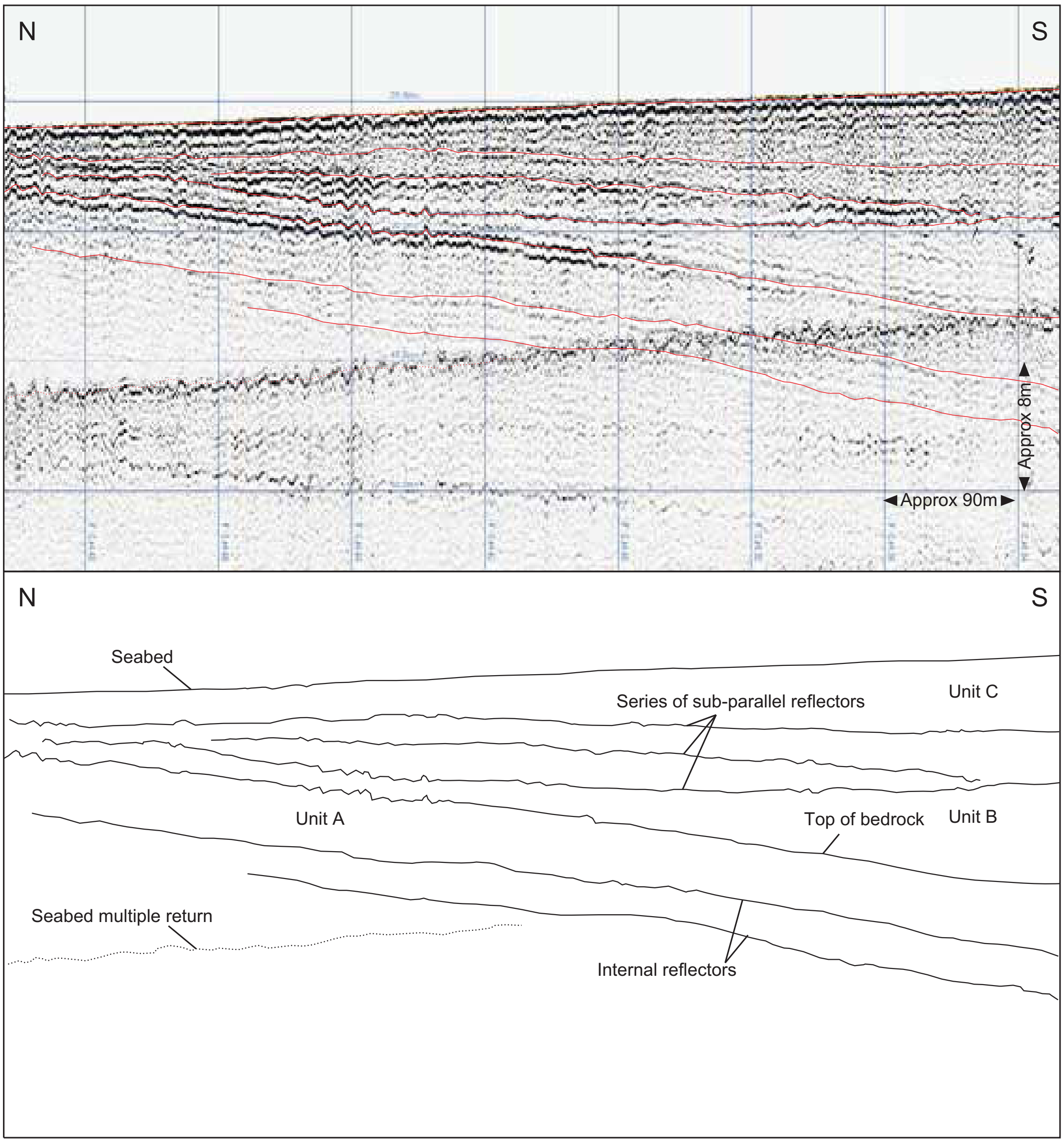
Happisburgh sidescan sonar mosaic with bathymetric contours

Figure VII.2





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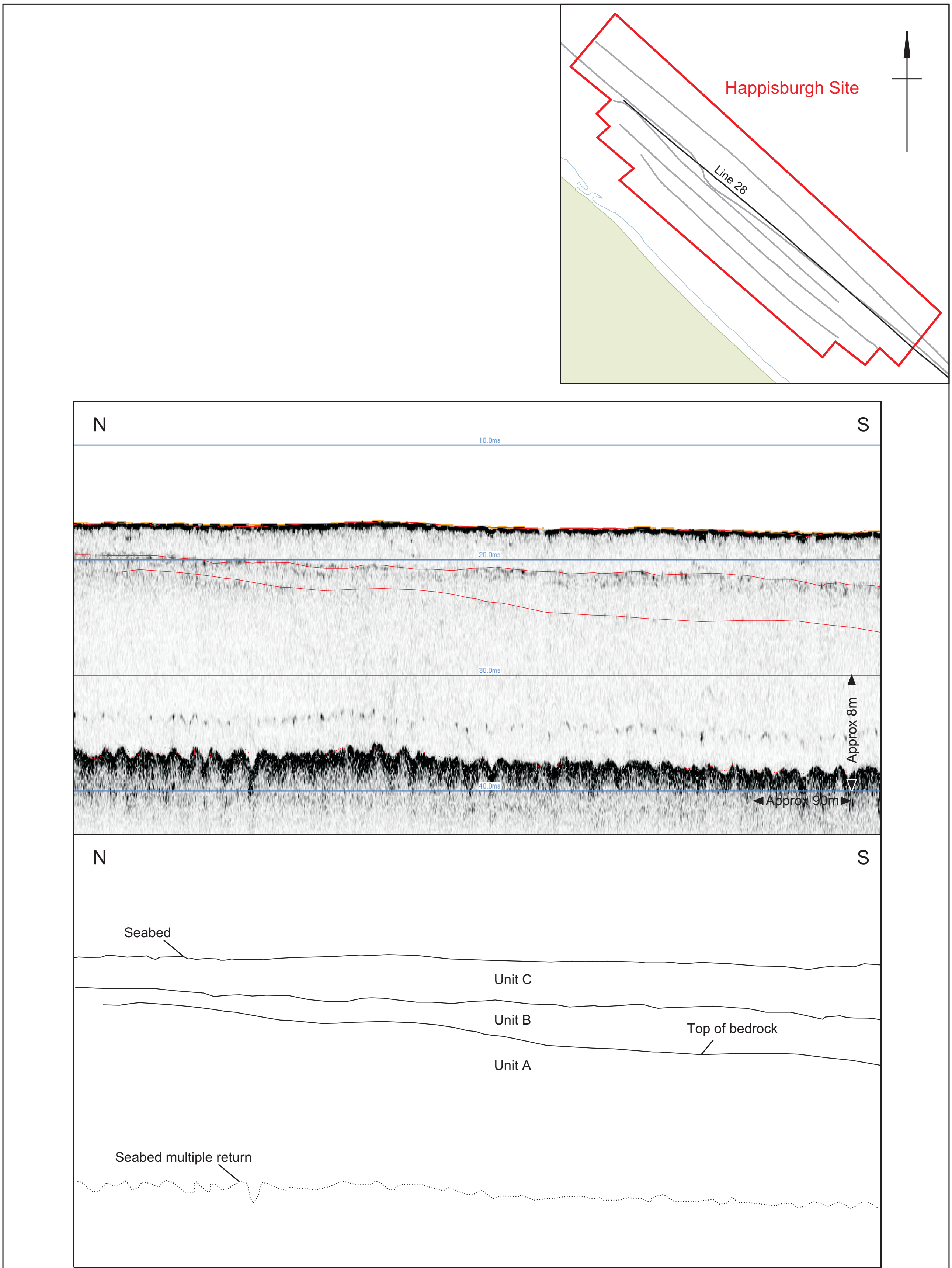
Boomer data example illustrating sediment units at Happisburgh

Figure VII.3



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Chirp data example illustrating sediment units at Happisburgh

Figure VI.4

Survey lines
Bathymetric contours (metres below OD)

0 500m

Drawing projection UTM WGS84 z31N

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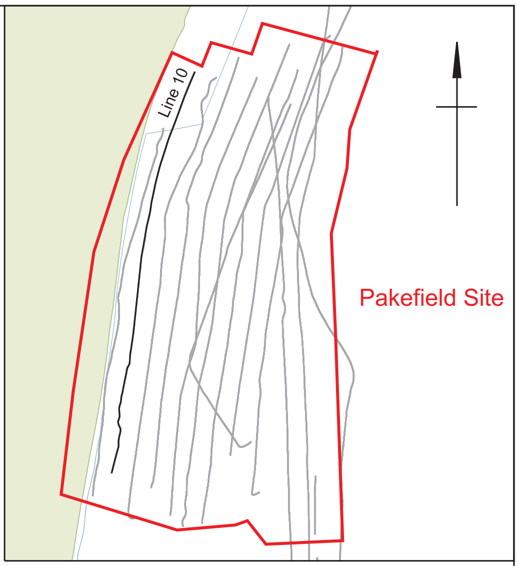
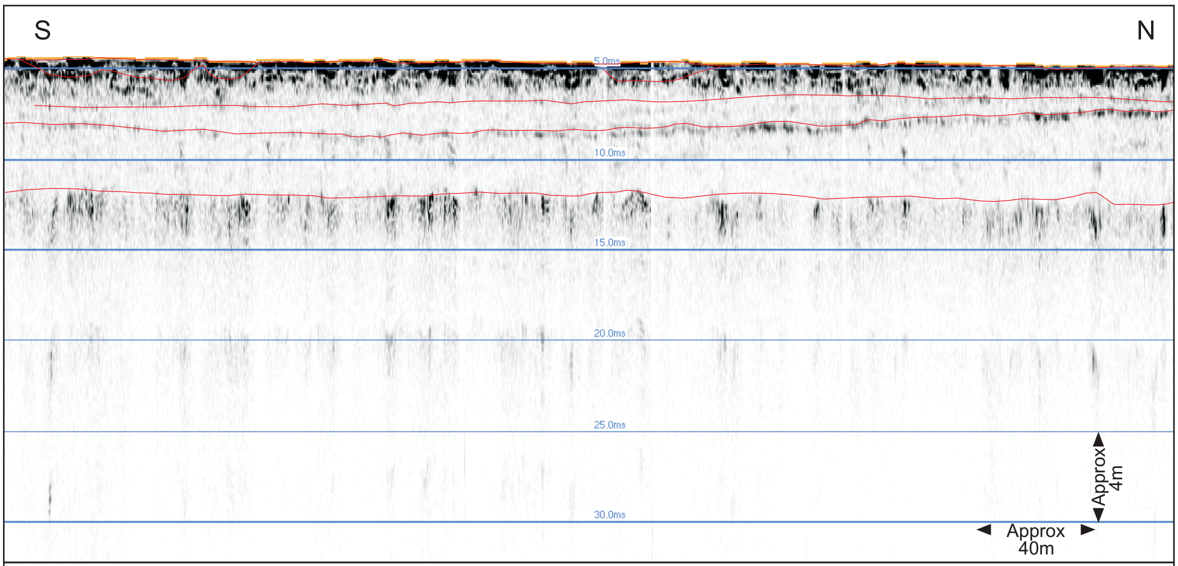
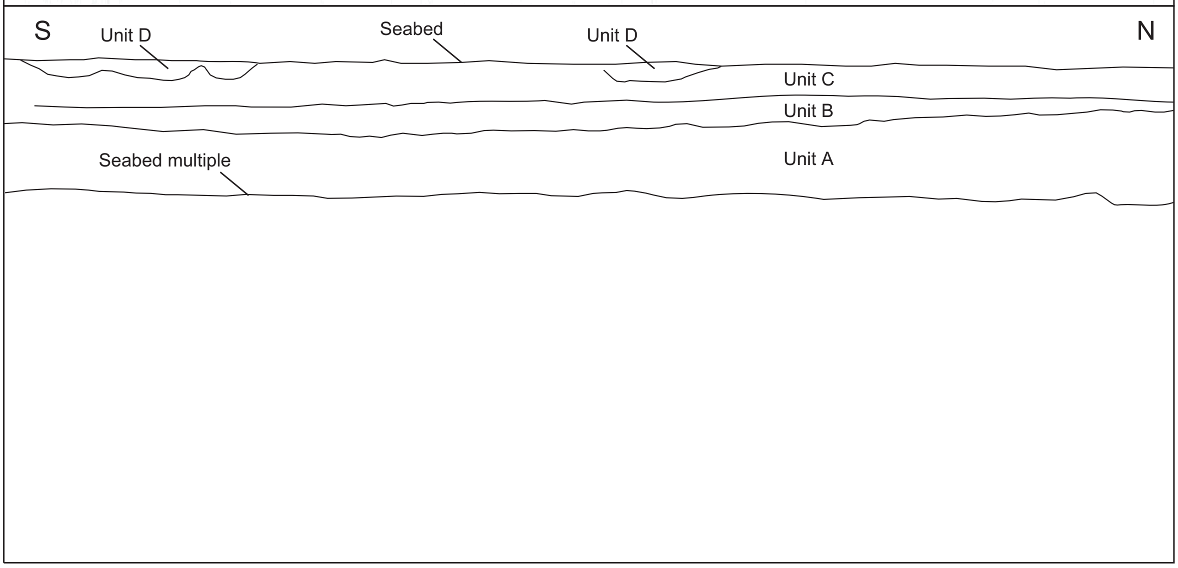
Pakefield sidescan sonar mosaic with bathymetric contours

Figure VII.5







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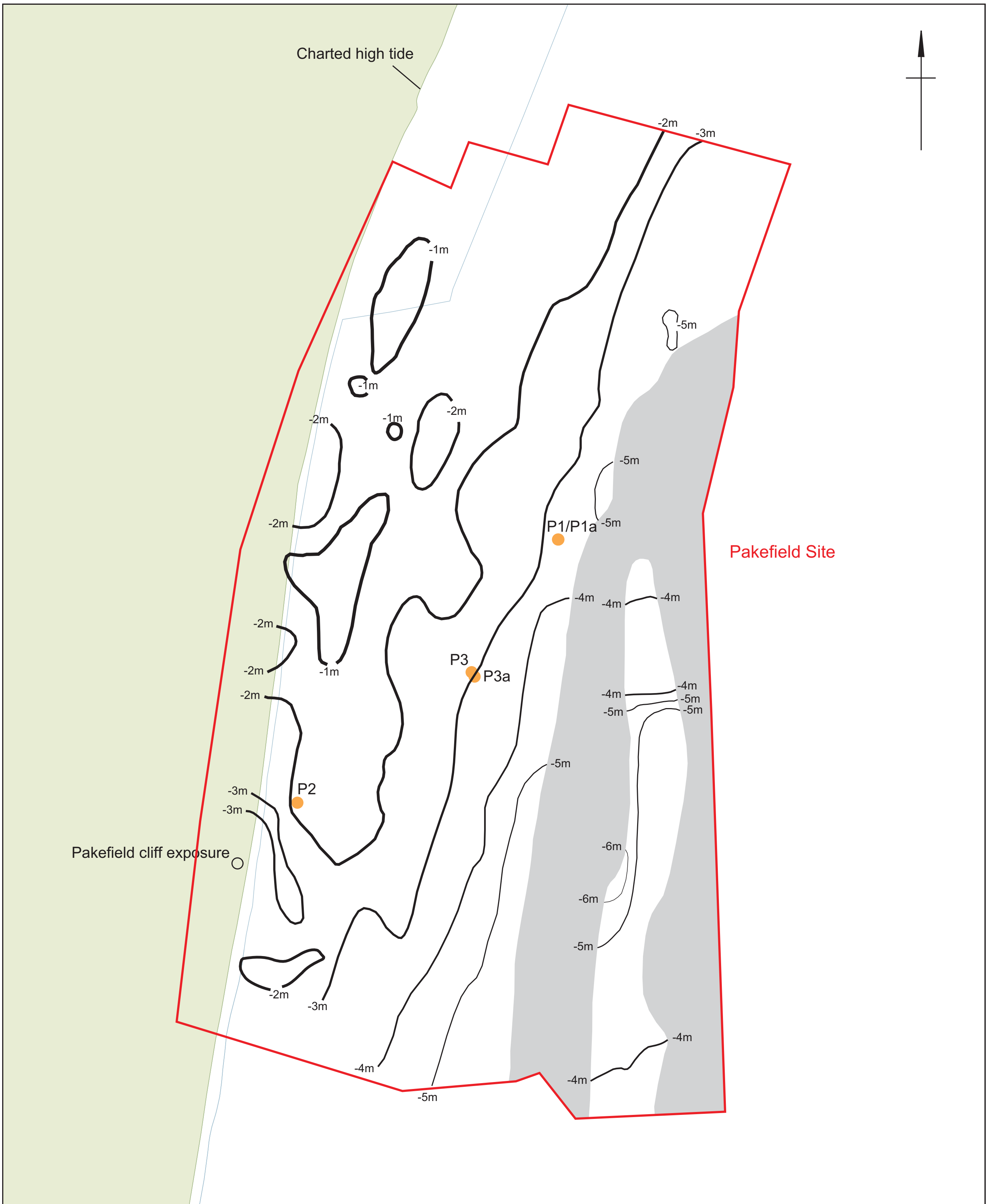
Chirp data example illustrating sediment units at Pakefield

Figure VII.6



- Vibrocore location
- Depth below seabed (in metres) to base of Unit C
- Data obscured by seabed multiple

0 500m

Drawing projection UTM WGS84 z31N

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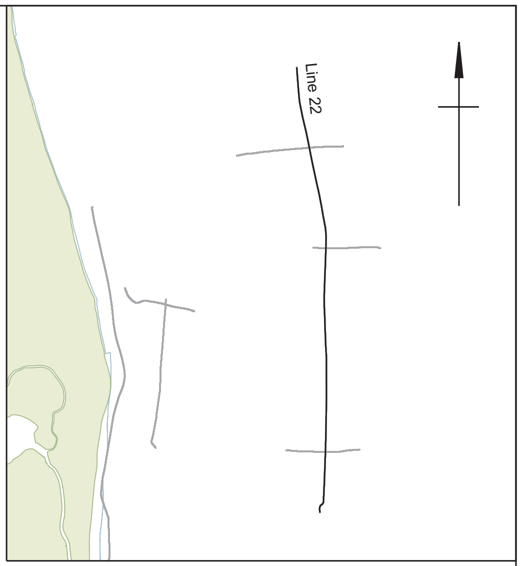
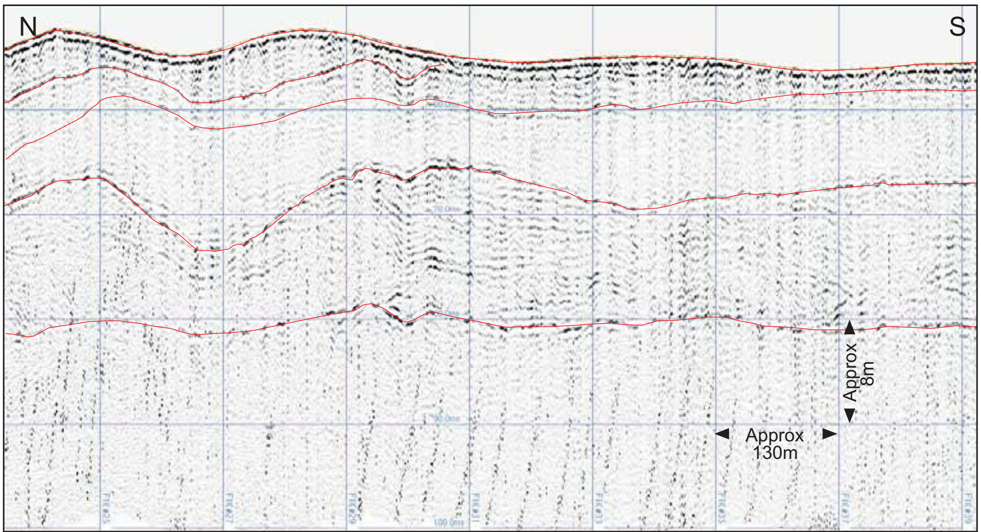
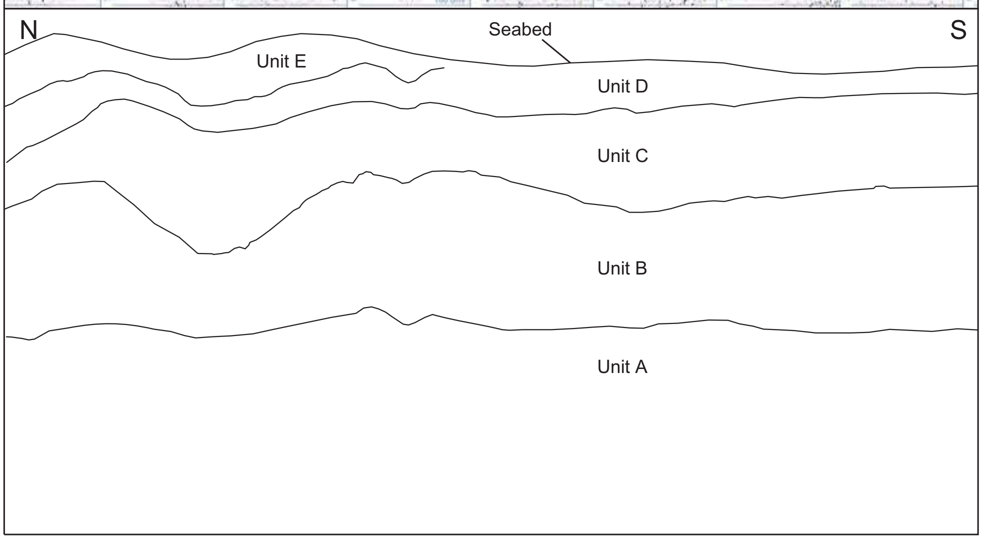
Depth (in metres) to the base of Unit B at Pakefield

Figure VII.7







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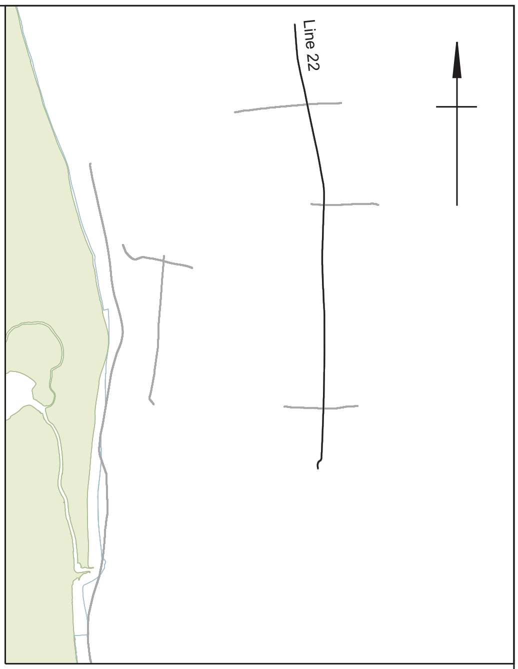
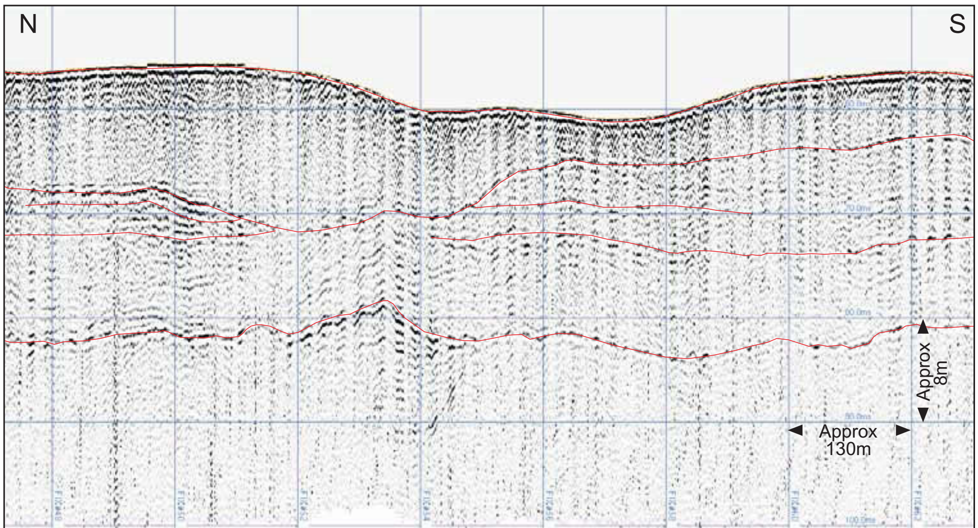
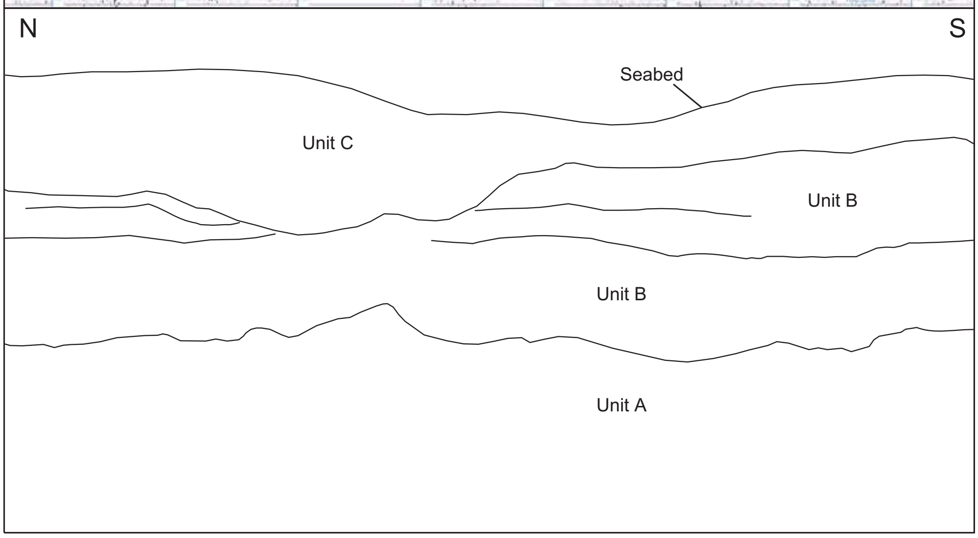
Boomer data example illustrating sediment units at Barley Picle

Figure VII.8







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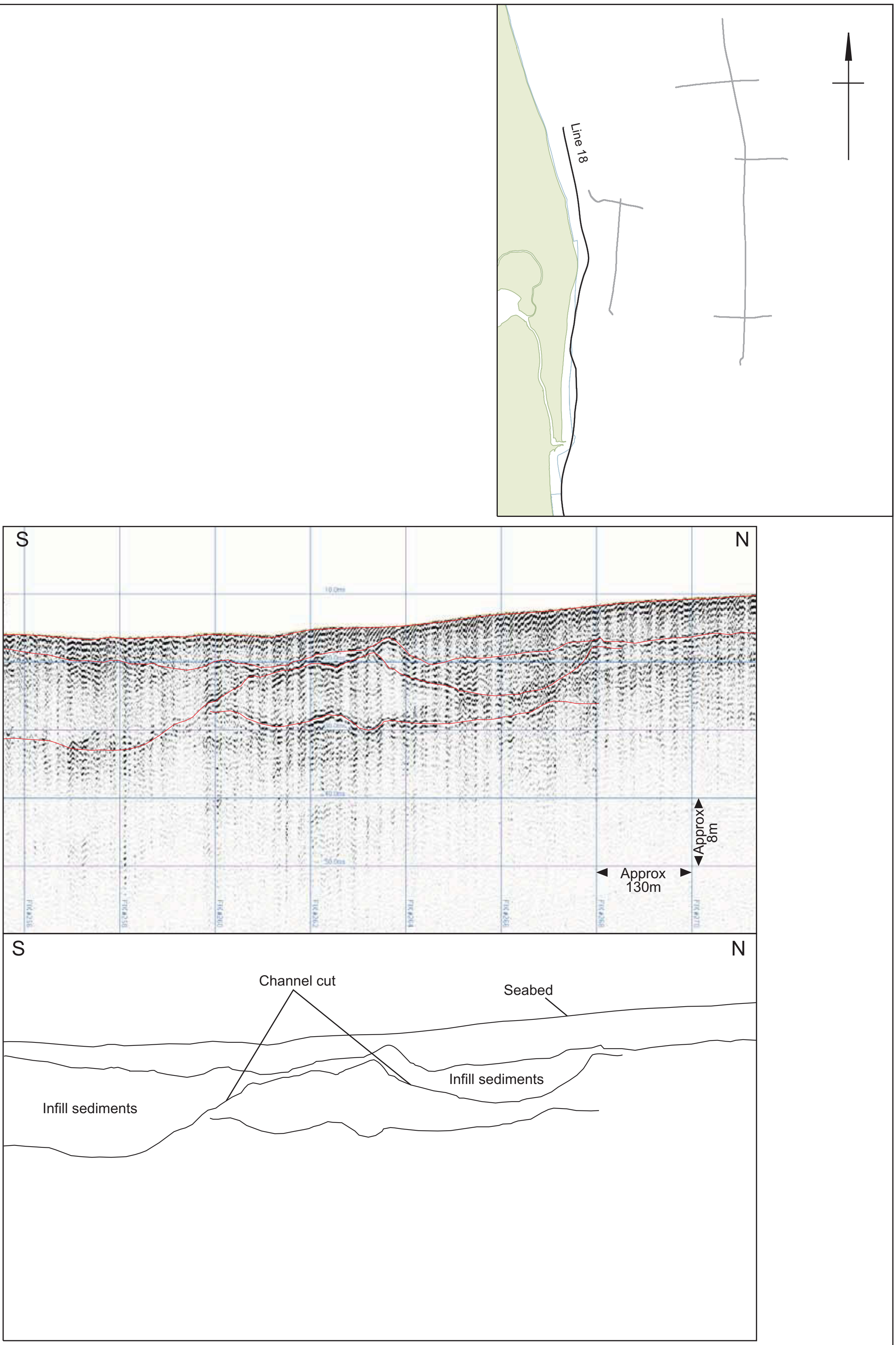
Evidence of a sediment unit (Unit C) cutting into underlying Unit B

Figure VII.9



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Wessex Archaeology

Channel cut and fill sequence observed offshore Great Yarmouth

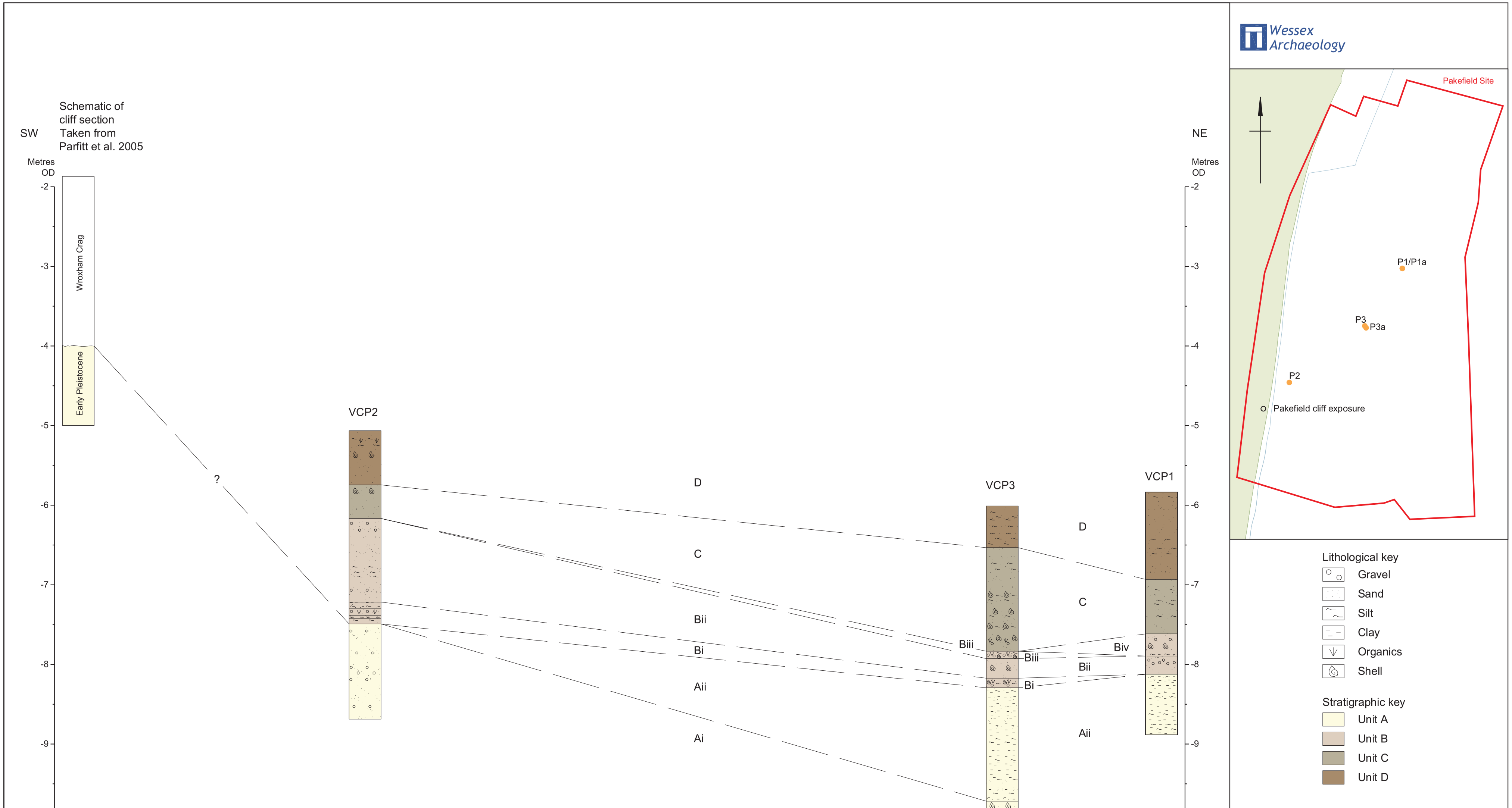
Figure VII.10

Plate 1. VCP1

Plate 1. VCP2

Plate 1. VCP3

Wessex Archaeology	Date:	01/12/06	Illustrator:	KJB/KMN
	Path:	W:\Projects\57422\Drawing Office\Report Figs\FINAL REPORTS\VOLUME 7		



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Illustrator:	KJB/KMN
Date:	26/01/07
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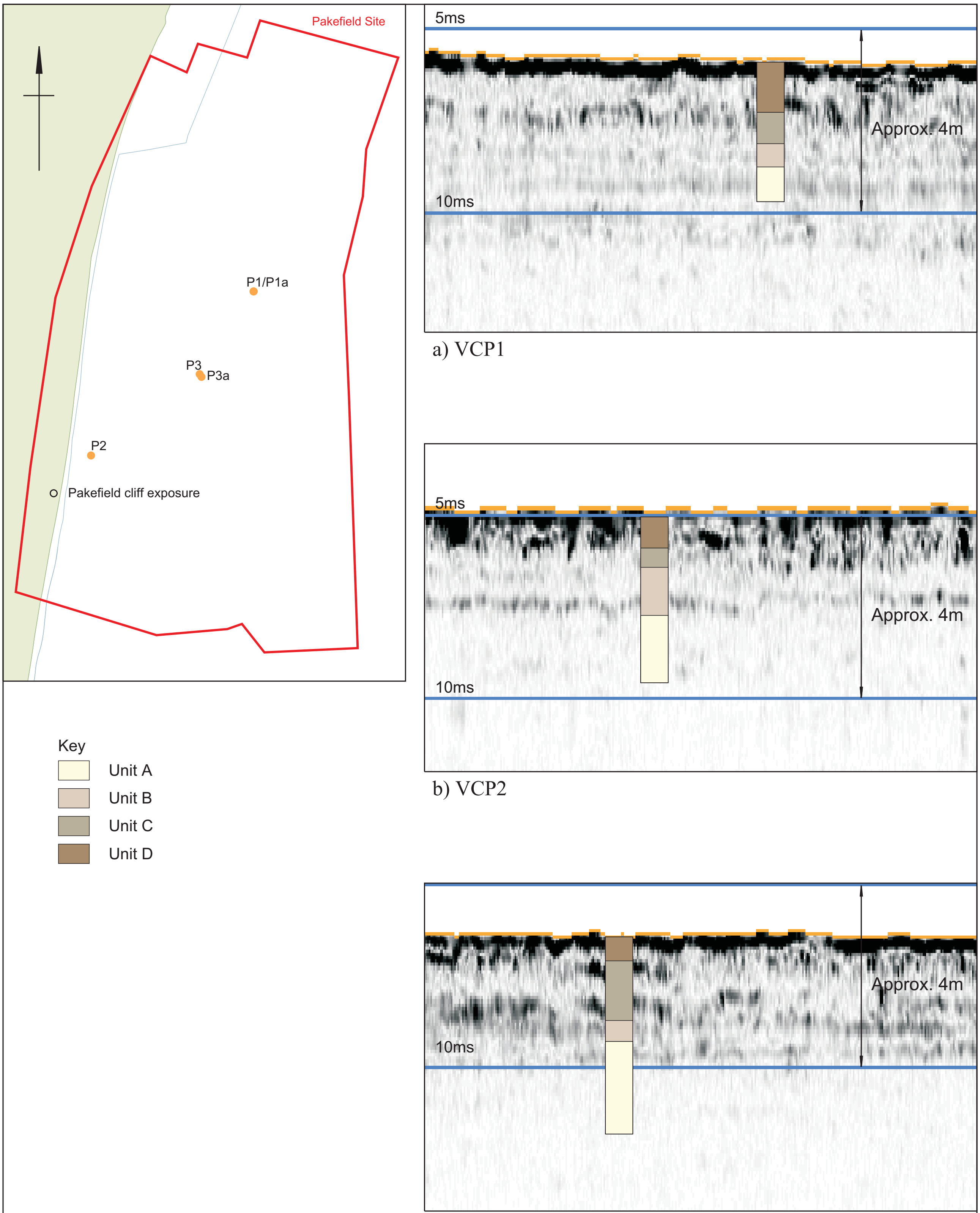
Vibrocore profiles and sedimentary units

Figure VII.12



Date:	01/12/06	Revision Number:	1
Scale:	Vertical 1:125 Inset 1:25000	Illustrator:	KJB/KMN
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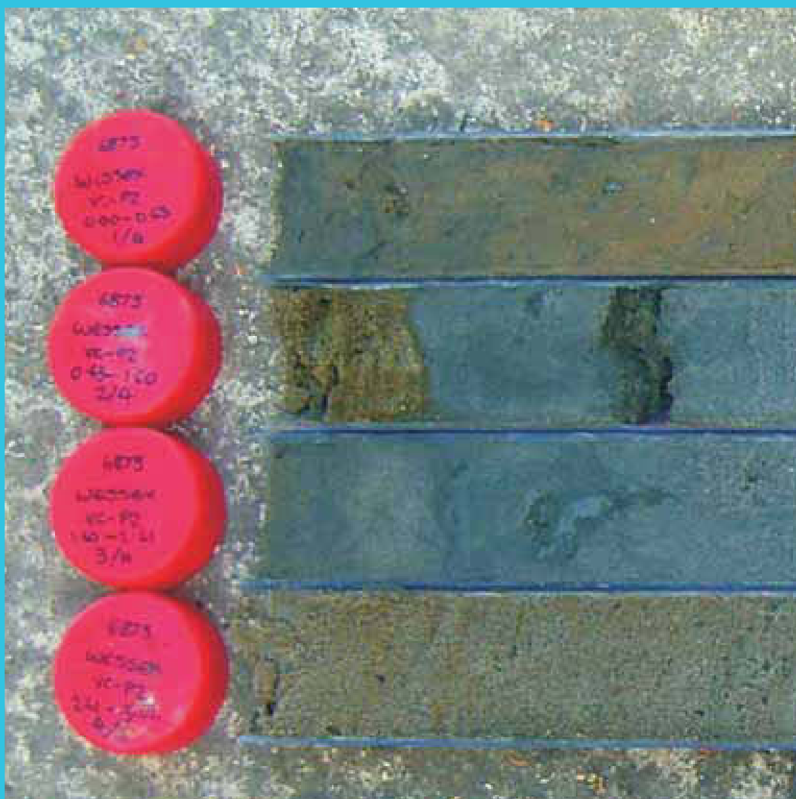
Vibrocore locations related to seismic data

Figure VII.13



WESSEX ARCHAEOLOGY LIMITED.
Head Office: Portway House, Old Sarum Park, Salisbury, Wiltshire SP4 6EB.
Tel: 01722 326867 Fax: 01722 337562 info@wessexarch.co.uk www.wessexarch.co.uk
London Office: Unit 113, The Chandlery, 50 Westminster Bridge Road, London SE1 7QY.
Tel: 020 7953 7494 Fax: 020 7953 7499 london-info@wessexarch.co.uk www.wessexarch.co.uk

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